THE NICKEL BULLETIN

A Monthly Summary of Recent Literature

JANUARY/FEBRUARY

1960 Volume 33 No. 1-2

THE MOND NICKEL COMPANY LIMITED

THAMES HOUSE MILLBANK LONDON SW1

Telephone: VICtoria 3888

INDEX

General — Page

Charpy V-notch Impact Testing: British Standard 1
British and Foreign Specifications for Steel Castings 1
Production of Raised Studs on Metal Surfaces by Spot Welding 1
Induction Brazing and Soldering 2

Nickel

Survey of Information on Fuel Cells 2
Charge/Discharge Process of the Nickel-Oxide Electrode 2
Adsorption Measurements on Nickel-Oxide Electrodes 2
Reaction Mechanism of Sealed Nickel-Cadmium Cells 3
Charging Characteristics of a Sealed Nickel-Cadmium Battery 3
Use of Polarised Neutrons to Determine Magnetic Scattering by Nickel 3
Nickel Catalysts in the Petroleum Industry 4
Production and Applications of Nickel Compounds 4
Determination of Alloying or Contaminant Elements in Electronic Nickel 4
„ „ Nickel in Nickel-Iron Alloys 5
„ „ „ „ Steel and Cast Iron 5

Electrodeposition and Other Coating Methods

Electrodeposited Coatings of Nickel and Chromium: Specification 5
Factors Influencing the Selection and Performance of Plating Anodes 5
Practical Aspects of Tin-Nickel Plating 6
Electrodeposition of Tin-Nickel Coatings 6
Nickel Immersion Plating of 'Zircaloy 2' 7
One-Coat Enamelling of Steel 7

Non-Ferrous Alloys

Machinable High-Density Tungsten-Nickel-Copper Alloys: Specification 7
Wrought Copper-Alloy Wire: Specification 8
Influence of Heat-Treatment on the Temperature Coefficient of Resistance of Copper-Nickel Alloy Wire 8
Use of Non-Ferrous Materials in Various Industries: Historical Reviews 8

Nickel-Iron Alloys

Review of Modern Ferromagnetic Materials 9
Anisotropy in the Magneto-Resistance of Nickel-base Alloys 9
Hard Magnetic Materials 9
Soft Magnetic Materials 9
Long-Term Stability of Permanent-Magnet Materials 10

Cast Iron

Properties and Applications of 'Ni-Hard' 11

Constructional Steels

Determination of Copper and Nickel in Low-Alloy Steels 11
Fatigue Properties of Notched Steel Specimens 11
Influence of Microstructure on Notch-Toughness of Steels 11
„ „ Phosphorus and Sulphur on Ductility and Impact-Resistance of Cast Steels 12
„ „ Trace Elements on Isothermal Embrittlement in Nickel-Alloy Steels 12
„ „ Nickel Content on the Ms Temperature of Nickel-Alloy Steels 13
Development of a Non-Embrittling Cadmium-Plating Process for High-Strength Steels 13
'Thermomagnadynamics': New Heat-Treatment for High-Strength Steels 13

Constructional Steels (*continued*) — Page

Case-Hardening of Nickel-Alloy Steels 14
Machining of Nickel-containing Ultra-High-Strength Steels 14

Heat- and Corrosion-Resisting Materials

Solid-State Reactions in Nickel-base High-Temperature Alloys 15
Reactions Involved in the Oxidation of Alloys 15
Oxidation Characteristics of Nickel-Chromium Alloys 15
Influence of Chromium Diffusion on the Oxidation of Nickel-base Alloys 16
Oxidation of Iron-Nickel Alloys 17
Internal Oxidation of Nickel-base Alloys 17
Relationship between the Microstructure and Mechanical Properties of Nickel Cermets 17
Influence of Melting Method on the Properties of a Nickel-base Heat-Resisting Alloy 18
Physical and Mechanical Properties of Precipitation-Hardenable Stainless Steels 19
Properties and Applications of '17-4 P.H.' Steel 19
Mechanical Properties of 'AM-350' and 'AM-355' Stainless Steels 20
Properties of 'Wilco-Wiggin Thermometals' 20
Fatigue Characteristics of 'Inconel' at High Temperatures 20
„ „ „ 'INOR-8' at High Temperatures 21
Sliding Characteristics of Nickel and Nickel Alloys at High Temperatures 21
Materials for High-Temperature Gear Applications 22
Development of Nickel-containing Seal Materials: High-Temperature Wear Tests 22
Heat-Resisting Coatings for Use on 'Thermold J' Tool Steel 22
Fuel-Oil-Ash Corrosion of Nickel-containing Heat-Resisting Alloys 23
Failure of Nickel-containing Heat-Resisting Alloys and Steels Used in Gas-Carburising Furnaces 24
Corrosion and Heat-Resistant Steel Plate: Specification 25
Properties of Cold-Rolled Austenitic Stainless Steel 25
Stainless-Steel Wire, Rivets, and Split Pins: Specification 25
Nickel-base Alloys and Stainless Steel: Literature Reviews 25
Metallurgical Factors Influencing Stress-Corrosion Cracking of Austenitic Stainless Steels 26
Effect of Partial Immersion on the Corrosion of Galvanic Couples 27
Atmospheric Corrosion of Ferrous Materials 27
„ „ „ Non-Ferrous Metals 27
Atmospheric-Corrosion Testing 28
Deterioration of Metals due to Air Pollution 28
Corrosion of Nickel and 'Inconel' in a Fused-Salt Environment 28
Corrosion Experience in Hydrometallurgical Refining of Nickel 28
Materials of Construction for Urea-Synthesis Plant 29
Materials Used in Railroad Tank Cars 29
Factors Influencing the Performance of Stainless-Steel Flexible Bellows Joints 30
Slip-Casting of Stainless-Steel and Nickel Powders 30
Electrolytic Etching of Stainless Steel 30
Determination of Aluminium in High-Temperature Alloys 31
Determination of Tantalum and Niobium in Stainless Steels 31
Resistance-Welding of Nickel-containing Materials 31
Welding of Dissimilar Metals by the Metallic-Arc Process 32
Welding of '17-4 P.H.' Stainless Steel 32

Analysis 32

Patents 33

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Charpy V-notch Impact Testing: British Standard

BRIT. STANDARDS INSTN.: 'Charpy V-notch Impact Test.'

B.S. 131: *Part* 2: 1959; 11 pp. Price 4/-.

The various sections of the Standard lay down requirements relating to: form and dimension of test piece, notch preparation, testing machine, method of testing and presentation of the results.

Summary of British and Foreign Specifications for Steel Castings

BRIT. STEEL CASTINGS RESEARCH ASSOC.: 'British and Foreign Specifications for Steel Castings. Part I.'

Published Dec. 1959; 48 pp. Price 40/-; $7.50.

The general increase in international trade has made it desirable for the steel founder to have to hand a summary of British and foreign specifications which would permit ready reference to the type of steel and the range of mechanical properties required. This publication was issued to make available in summary form the main requirements laid down for steel castings by the National Standardising Organisations in various countries. Private and semi-confidential specifications and designations of grades internally adopted by steel-producing companies are not included.

Part I of the brochure covers the following countries: Austria, Belgium, France, East Germany, West Germany, Great Britain, Sweden, Switzerland and the U.S.A. (The designations of standards current in Czechoslovakia, Holland and Italy are also listed.) The information given is that available on June 30, 1959. Part II of the publication will summarise specifications relating to requirements in Commonwealth countries and additional foreign countries.

The publication contains: lists of the specifications issued by the countries covered; a list of grade designations often used without reference to the number of the parent specification; and (in the main section) a tabular summary of the scope and compositional and property requirements of the specifications of each country covered. This last section includes reference to the nearest equivalent British specifications, though it is emphasised that this reference is intended to serve only as a rough guide.

Attention is drawn to the fact that the properties quoted in specifications originating from different countries will differ according to the form and geometry of the test piece used, and, in this connection, the dimensions of typical test pieces used in the countries covered are summarised in an appendix to the publication.

Production of Raised Studs on Metal Surfaces by Spot Welding

E. J. FRENCH: 'Raising of Studs on Metal Surfaces.'

Brit. Welding Jnl., 1959, vol. 6, Dec., pp. 595–8. *Report A3/2/58* issued by the *British Welding Research Association* to members in May 1959.

In making a spot weld the constraint upon the molten weld metal may, if the applied electrode force is too low, or if the welding current is too high, be insufficient to prevent its violent expulsion between the members being welded. Sometimes, with high current densities, this phenomenon of splashing may occur at the surface in contact with the electrodes, at the interface between the pieces of metal being welded, or at both surfaces. Splashing causes lower spot-weld strengths by destroying the continuous peripheral zone from which most of the strength accrues. It causes voids and cavities in the weld and disfigures the welded product. Patent applications have recently been filed, by the U.K. Atomic Energy Authority, covering a new process in which the splashing is controlled. Instead of the molten metal's being expelled outwards from the weld, it is directed into a cavity in the face of the electrode, where it freezes to form a protuberance, of a predetermined shape, welded to the parent metal. Since the periphery of the weld is not disturbed, not only is the expelled metal employed to form the required shape, but, by suitable control of the welding variables, the disadvantages normally associated with splashing are avoided.

Normally, the metal required to form the stud is obtained from the molten zone produced at the interface between the parts being welded, but protuberances of limited size have been raised from a single sheet of metal. Cylindrical studs have been formed in a range of ferrous and non-ferrous materials (including 18-8 stainless steel, 'Fortiweld', 'Corten', aluminium and magnesium, and the 75, 80A and 90 grades of the 'Nimonic' series). Studs of more complex shape may be produced, and studs may also be cast around metallic or non-metallic inserts. Among the possible applications of the new process is the forming of projections in thick material in preparation for projection welding.

Details of the technique and of the types of stud obtainable are given in the paper.

Induction Brazing and Soldering

J. LIBSCH and P. CAPOLONGO: 'High-Frequency Induction Brazing and Soldering.'

Welding Jnl., 1959, vol. 38, Nov., pp. 1059–69.

In recent years complex forgings and stampings in many materials have been redesigned, with considerable saving in cost, to permit their manufacture by the assembly, by brazing or soldering, of mass-produced component parts. Brazing and soldering techniques have also permitted the construction of assemblies too costly or complex to be produced by other processes. For many reasons, not the least of which are the rapid heating and precise heat control obtainable, induction heating has proved a valuable aid in such joining processes. The advantages of high-frequency induction heating are fully realised, however, only by suitable adaptation of the brazing or soldering procedures used and of joint design. The factors to be taken into account for optimum results are outlined in the present paper.

The compositions and melting ranges of soldering and brazing alloys commonly used in association with induction-heating techniques are listed, and consideration is given to the selection of the most suitable alloy for use with such basis materials as carbon and alloy steels, stainless steel, copper and copper alloys, nickel and nickel alloys, aluminium alloys. Brazing and soldering fluxes are briefly discussed, and in the other sections of the review notes are given on joint design, choice of suitable induction-heating generators, the fixtures required, and typical applications.

NICKEL

Survey of Information on Fuel Cells

B. R. STEIN: 'Status Report on Fuel Cells.'

U.S. Army Research Office, Report ARO–1, June 1959; 116 pp.

The report is the first in a series which will collate and review all available information relevant to an assessment of the present status of research and development work on fuel cells. In this first report the more important basic facts are noted, and an attempt has been made to develop a comprehensive *bibliography* for reference purposes.

After an outline of military requirements and a general description of the basic components of the fuel cell, notes are given on the salient features and state of development of the following fuel-cell systems: hydrogen/oxygen, molten-salt, Redox, regenerative, consumable-electrode, and that employing an ion-exchange membrane as the electrolyte. A review is made of the U.S. Department of Defense programme in support of fuel-cell development.

Appendices to the report cover: definitions; data available on the characteristics of known fuel-cells (including those incorporating nickel electrodes) which fall within the classifications outlined in the body of the report; availability, production and storage of the fuels required (hydrogen, oxygen and carbon monoxide); information on U.S. Government contracts.

Symposium on Nickel-Cadmium Batteries

'Proceedings 12th Annual Battery Research and Development Conference, 1958.'

Published by the *Battery Conference Committee, Power Sources Division, U.S. Army Signal Research and Development Laboratory*, Fort Monmouth, N.J., 1959; 134 pp.

The Battery Research and Development Conference, which is sponsored by the Power Sources Division, U.S. Army Signal Research and Development Laboratory, is held each year to present and discuss the results of research by Government, university and industrial organisations. The Proceedings of the 12th Annual Conference cover five symposia: on fuel cells, nickel-cadmium batteries, special-purpose batteries, primary batteries, and power sources of the future. The scope of the four papers presented in the Symposium on Nickel-Cadmium Batteries is indicated below.

Charge/Discharge Process of the Nickel-Oxide Electrode

F. KORNFEIL: 'The Charge-Discharge Process of the Nickel-Oxide Electrode', pp. 18–22.

The mechanism of the reaction occurring during the charge and discharge of the nickel-oxide electrode in alkaline cells has been the subject of considerable research. The theories published by FOERSTER and ZEDNER during the years 1905–10, which have been generally accepted as a correct interpretation of the charge/discharge reaction, do not agree in certain respects with results obtained in more recent investigations (to which reference is made in the present paper), and the work now described was initiated to obtain a quantitative elucidation of the electrode reaction.

Since it is possible separately to determine, by addition of a reference substance, changes in H_2O and KOH during operation of the electrode, this analytical procedure was used by the author. The nickel-oxide electrodes studied were sintered nickel plates taken from nickel-cadmium batteries. Details are given of the procedures and apparatus used, and the equations arrived at are fully discussed.

Adsorption Measurements on Nickel-Oxide Electrodes

B. C. BRADSHAW: 'Adsorption Measurements on Nickel-Oxide Electrodes', pp. 22–5.

In the experiments reported the quantity of alkali taken up from, or given up to, the solution by the various oxides of nickel on the electrode was determined maintaining the following variables constant:

(*a*) the number of molecules of water, per nickel atom, taken up from, or released to, the solution by the nickel-oxide electrode during charge or discharge; (*b*) the amount of water, if any, that is produced or consumed at, or on, the nickel-oxide electrode during charge or discharge. Charged nickel-oxide electrodes were found to adsorb about 6 mg. of KOH per gram from solutions ranging in concentration from 0·05–3·0 *N*. Uncharged electrodes did not, however, adsorb a measurable quantity of KOH from the solutions at the concentrations studied.

Investigation of the author's assumption that the reaction was limited to the surface of the charged plates, and was a measure of the surface area, showed that the area of charged nickel electrodes, as measured by the B.E.T. method, was in good agreement with that calculated on the basis of the amount of KOH adsorbed by the electrode. The energy of adsorption of the KOH was about 4×10^{-13} erg, and it is concluded that the ions were physisorbed.

Reaction Mechanism of Sealed Nickel-Cadmium Cells

E. G. BAARS: 'The Working Mechanism of Sealed Nickel-Cadmium Cells', pp. 25–7.

In a previous paper, outlining experiments concerned with the reaction mechanism governing the operation of sealed nickel-cadmium cells, it was concluded that a chemical interaction occurs between the spongy cadmium of the negative electrode and the oxygen liberated at the positive. It was felt that this one reaction enabled the system to function completely sealed, and the rules governing the reaction, established experimentally, led to the practical consequence that any design facilitating the access of oxygen to the cadmium surface was considered favourable to the efficiency of oxygen consumption in sealed cells.

As a result of a thorough analysis of pertinent patent specifications and further experimental observations, the author has come to the conclusion that the oxygen-consuming reaction in a sealed cell is electrochemical rather than chemical in nature. According to this concept, oxygen is 'activated' on the surface of many metals, carbon, or presumably any electronically-conducting material immersed in an alkaline electrolyte. In this paper the reactions involved are discussed, experiments are referred to in confirmation of the proposed mechanism, and the practical significance of the concept is considered.

Charging Characteristics of a Sealed Nickel-Cadmium Battery

L. BELOVE and I. M. SCHULMAN: 'Charging Characteristics of a Sealed Sintered Plate Nickel-Cadmium Battery', pp. 27–30.

The paper summarises the charging characteristics of 'C' cell sealed rechargeable nickel-cadmium batteries manufactured by Sonotone Corporation. The 'C' cell, which utilises the cylindrically-rolled-plate type of construction, is placed into a drawn can (the negative electrode) which requires sealing at only one end. Compared with that of previous types, in which both ends of the cylinder were sealed, this design permits use of a thinner wall and increases the capacity of the cells by up to 40 per cent. Particular emphasis is being placed on determination of the potential of such cells for applications involving continuous temperature cycling. The information presented, obtained at three temperatures (0°, 75°, and 125°F.: −18°, 24° and 50°C.), includes capacity data, data on charging characteristics under constant-potential conditions, and voltage/time curves for various charging rates.

Use of Polarised Neutrons to Determine Magnetic Scattering by Nickel

R. NATHANS, C. G. SHULL, G. SHIRANE and A. ANDRESEN: 'The Use of Polarised Neutrons in Determining the Magnetic Scattering by Iron and Nickel.'

Jnl. Physics and Chemistry of Solids, 1959, vol. 10, July, pp. 138–46.

The investigation described was initiated in view of the advantages offered by the use of polarised beams of neutrons in diffraction studies of magnetic materials. The report (1) summarises experience gained in modifying a typical neutron-diffraction spectrometer to polarised-beam applications, and (2) presents experimental data obtained using the technique to determine the absolute magnetic scattering of the ferromagnetic elements iron and nickel.

The procedures employed for the production and use of polarised beams of monochromatic neutrons are outlined, and data are presented on the performance of two polarising crystals (Fe_3O_4 and a 92-8 cobalt-iron alloy). Data obtained on the intensity of reflection exhibited by single crystals of iron and nickel for incident neutron beams of different polarisation were used to determine the magnetic-scattering amplitudes at various scattering angles, and a comparison is made between the observed magnetic form of values and theoretical values derived from calculated 3*d* wave functions.

Sliding Characteristics of Nickel at High Temperatures

See abstract on p. 21.

Corrosion Experience Gained in Hydrometallurgical Refining of Nickel

See abstract on p. 28.

Corrosion of Nickel in a Fused-Salt Environment

See abstract on p. 28.

Effect of Partial Immersion on the Corrosion of Galvanic Couples

See abstract on p. 27.

Nickel Catalysts in the Petroleum Industry

P. D. WILMOT: 'Nickel and Cobalt Catalysts in the Petroleum Industry.'

MOND NICKEL CO., LTD., *Publn.* 1680*.

Reprint from *Petroleum*, 1958, vol. 21, June, pp. 187–90, 200; July, pp. 225–8, 254.

See abstract in *Nickel Bulletin*, 1958, vol. 31, No. 8, p. 214.

Production and Applications of Nickel Compounds

J. G. DEAN: 'The Industrial Growth of Nickel Compounds.'

Industrial and Engineering Chemistry, 1959, vol. 51, Oct., pp. 40A–5A.

In the U.S.A. in 1957 approximately 10,000,000 lb. of nickel, out of a total consumption of 245,000,000lb., were used in the form of chemical derivatives. Such nickel compounds serve as a basic raw material for a variety of key industries, and, although less than 5 per cent. of the total nickel produced is consumed in the form of compounds, this relatively small percentage has an importance far beyond the actual amount involved: for example, the weight and value of the product obtained in catalytic applications often exceed by one thousand times the weight and value of the nickel required for the catalyst. In this article the author reviews the applications and production of the more important nickel compounds.

Nickel compounds find application in five main fields: catalysts, nickel plating, ceramics, alkaline storage batteries, and electronics. These applications, and the compounds relevant to each, are discussed in the first section of the review. The second section, which contains notes on the production of the main nickel compounds, is concerned with: sources of nickel; nickel oxide; nickel sulphate, nickel nitrate and nickel chloride; nickel basic carbonate and nickel hydroxide; nickel formate, nickel oxalate and nickel acetate; and miscellaneous nickel compounds (nickel carbonyl, nickel sulphide and subsulphide, nickel ammonium sulphate, nickel sulphamate, nickel soaps and nickel dialkyldithiocarbamates). The review ends with brief comments on the composition and cost of the more commonly used compounds.

Slip-Casting of Nickel Powders

See abstract on p. 30.

Chemical Determination of Alloying or Contaminant Elements in Electronic Nickel

T. R. ANDREW and C. H. R. GENTRY: 'The Analysis of Nickel. Part I. Chemical Methods.'

Metallurgia, 1959, vol. 60, July, pp. 27–30; Aug., pp. 69–72; Sept., pp. 121–4; Oct., pp. 173–6.

In the radio-valve industry the efficient manufacture of reliable valves and tubes is dependent upon careful control of the 'electronic nickel' used for the cathodes, anodes and other component parts. The term 'electronic nickel' is used to designate pure nickel, or low-alloy nickel, falling within the composition range listed below.

Element	*Range %*
Aluminium	0·001–0·1
Carbon	0·001–0·1
Chromium	0·03 max.
Cobalt	0·01–1
Copper	0·005–0·2
Iron	0·005–0·2
Magnesium	0·001–0·1
Manganese	0·001–0·2
Phosphorus	0·02 max.
Silicon	0·001–0·3
Sulphur	0·01 max.
Titanium	0·001–0·05
Tungsten	4 max.
Zinc	0·01 max.

Almost all the constituents listed have some influence, beneficial or adverse, on the performance of the component, and their control is of obvious importance. The present paper gives details of analytical techniques formulated for each element on the basis of a re-examination of the chemical methods published in the literature (the *bibliography* contains 95 items).

An indication of the scope of the paper may be obtained from the authors' introductory comments:

'Although most of the methods to be given require a sample weight of either 0·1 or 0·25 g., they have been designed so that they can be adapted to samples weighing only 10 mg. by suitable choice of aliquot or final volume of solution.

'For routine control purposes, the analysis of electronic nickel is preferably carried out spectrographically, and suitable methods for this will be given, as Part II of this paper, by G. P. MITCHELL and G. ORME. The present paper is concerned with chemical methods (mainly photometric) which might be used for referee purposes, for occasional determination of an element not normally analysed spectrographically, or in laboratories where spectrographic facilities are not available. Although the methods have been developed particularly for electronic nickel, they are obviously equally applicable to nickel used for other purposes, for example, in electroplating or in the chemical, food or electrical industries. They are also often applicable to nickel-rich alloys generally.

'In the present paper, each of the elements listed in the table (see above) will be considered in turn. In each case, after a brief survey of the literature, an indication will be given of the methods which have led to the one preferred. This will be described in detail, with a note of any possible interferences, the time required for a determination,

We shall be pleased to supply a free copy of this publication.

and a realistic appraisal of the accuracy based on replicate determinations on a range of samples analysed under routine conditions.'

Determination of Nickel in Nickel-Iron Alloys

R. PRIBIL and M. KOPANICA: 'Chelometric Titration of Nickel in Nickel Pellets and Nickel-Iron Alloys.'
Chemist-Analyst, 1959, vol. 48, Sept., pp. 66-8.

The chelometric method described is claimed to provide a rapid and highly selective means of determining nickel in materials containing negligible amounts of cobalt.

Triethanolamine, a good masking agent for iron, has been suggested for the EDTA titration of nickel in the presence of iron. A colourless solution containing the iron (III)-triethanolamine complex is obtained by adding both the EDTA solution and the triethanolamine to a weakly acidic solution containing iron (III). (An intensely brown precipitate is first formed which, on addition of sodium-hydroxide solution, dissolves to yield a completely colourless solution.) It is unnecessary to bond all of the iron with EDTA: about one-third of an equivalent is sufficient. Use is made of this masking technique in the work described, and hence nickel is complexed with EDTA and can be back-titrated. (The indicator 'Thymolphthalexon', which is not adversely affected by the iron (III)-triethanolamine complex, is suitable, with a calcium-chloride solution as back-titrant.) Aluminium is also masked, as is manganese in part. In the back-titration, copper and zinc and the last traces of manganese are quantitatively displaced from the EDTA and held by the triethanolamine. Small quantities of cobalt are also converted to a triethanolamine complex during the titration, and, in addition, even high concentrations of copper can be masked in the alkaline medium by the addition of thioglycolic acid.

Procedures and typical results are given for determination of nickel in nickel pellets, iron-nickel alloys, and synthetic solutions containing iron, nickel and copper.

Determination of Nickel in Steel and Cast Iron

INSTITUT BELGE DE NORMALISATION: 'Determination of the Nickel Content of Steels and Cast Irons.'
Belgian Standard NBN 535, 1959; 8 pp.

The Standard covers a gravimetric method for determination of nickel in steels and cast irons with nickel contents higher than 0·5 per cent. The sample is dissolved in a mixture of hydrochloric, nitric and perchloric acids, and the insoluble elements are then separated by filtration. The iron is complexed with tartaric acid, and the nickel is precipitated by addition of an alcoholic solution of dimethylglyoxime. The precipitate is dried and weighed, and the nickel content of the sample is deduced from the value obtained.

Two procedures are laid down for application of the technique: for use where the cobalt content of the steel or cast iron is (1) less than and (2) greater than a third of the presumed nickel content.

Induction Brazing and Soldering

See abstract on p. 2.

Welding of Dissimilar Metals by the Metallic-Arc Process

See abstract on p. 32.

ELECTRODEPOSITION AND OTHER COATING METHODS

Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-base Alloys: Specification

AMER. SOC. TESTING MATERIALS: 'Standard Specifications for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-base Alloys.'
A.S.T.M. Designation B 142-59.

Supplement to Book of A.S.T.M. Standards, Including Tentatives, Part II, Non-Ferrous Metals, 1959, pp. 143-6.

The specification lays down requirements for coatings (electrodeposited on zinc or zinc-alloy components) which include a final coating of nickel or chromium and are intended for service in which both appearance and corrosion-resistance are important.

Four types of coatings are covered (Type DZ, Type FZ, Type KZ and Type QZ), the thickness requirements of which are listed in a table which is reproduced on p. 6. These requirements relate to the thickness of coatings on significant surfaces (which, it is suggested, may be defined as the visible surfaces which can be touched by a sphere of a diameter agreed between the manufacturer and the purchaser). By agreement between manufacturer and purchaser, copper may be omitted from coatings of Types DZ, FZ and KZ, in which case the nickel thickness required is that prescribed for copper + nickel. Details are given of the salt-spray test used to assess corrosion-resistance and of methods specified for determination of thickness.

Factors Influencing the Selection and Performance of Plating Anodes

D. J. FISHLOCK: 'Plating Anodes.'
Metal Industry, 1959, vol. 95, Oct. 2, pp. 162-6; Oct. 9, pp. 177-80.

The author emphasises in the introduction to this review that, with the exception of faulty pre-treatment, malfunctioning of the anodes is responsible for more plating troubles than any other factor. To function properly a plating anode should (1) dissolve freely and uniformly over a wide range of plating conditions, with no tendency to disintegrate, polarise or passivate; (2) be highly conductive (to minimise loss of power); and (3) be of high-purity (to prevent solution

Thickness Requirements for Nickel/Chromium Electrodeposits

(*See abstract, p. 5*)

Coating	Thickness of Coating, ‡ in.			
	Type DZ	Type FZ	Type KZ	Type QZ
Copper plus nickel,* min.	0·0020 (51 μ)	0·0012 (30 μ)	0·00075 (19 μ)	0·00050† (13 μ)
Copper, min.	0·00020 (5·1 μ)	0·00020 (5·1 μ)	0·00020 (5·1 μ)	0·00020 (5·1 μ)
Final nickel,* min.	0·0010 (25 μ)	0·00050 (13 μ)	0·00030 (7·6 μ)	0·00030 (7·6 μ)
Chromium (if required), min. ..	0·000010 (0·25 μ)	0·000010 (0·25 μ)	0·000010 (0·25 μ)	0·000010 (0·25 μ)

* The term nickel as used in these specifications includes nickel-cobalt alloys in which the nickel is the major constituent.

† Total of 0·00030 in. (7·6μ) if alternative of nickel only is used.

‡ The thicknesses given in the table are based on tests and experience with composite coatings in which matte nickel was deposited from a Watts-type bath and buffed prior to conventional bright-chromium plating. If these conditions are altered, different thicknesses may be required to give equivalent performance.

contamination). The satisfaction of these three requirements is briefly discussed in relation to type (cast, rolled, extruded and electrolytic anodes), shape and composition of the anode. The main body of the paper is concerned with a more detailed consideration of the types of anode used in alloy, copper, nickel and chromium plating, of the factors which influence selection of a particular type of anode, and of the precautions which must be taken to ensure satisfactory performance.

Notes on alloy anodes (including soluble alloy anodes, separate soluble anodes of the individual alloy constituents, and inert anodes) are followed by a section relating to anodes used in copper plating. In the next section an outline is given of the advantages and limitations of depolarised, carbon and electrolytic anodes used in nickel plating, and discussion, in this connection, of the formation of anode slime leads the author to outline the various types of anode bag and diaphragm used to prevent such slime from contaminating the plating solution.

The remainder of the review is concerned mainly with a discussion of the reasons for, and the factors and problems involved in, the use of inert anodes. The use of this type of anode in chromium plating is reviewed, and reference is made also to the applications of steel, lead, carbon and titanium anodes. In certain cases, insoluble anodes can be employed to good effect in nickel plating: in the present paper the advantages involved are illustrated by reference to the plating procedure developed for production of a thick deposit of high-grade nickel on the internal surface of long, small-bore tubes. The review ends with a *résumé* of the salient features and uses of contoured, auxiliary and bipolar anodes.

The paper includes tables giving typical analyses of plating anodes, referring to relevant British Standards, and making recommendations with respect to the types of anode for use in various nickel, copper, tin, speculum, tin-nickel, tin-zinc, cadmium, zinc, chromium, silver, gold, and rhodium plating solutions.

Practical Aspects of Tin-Nickel Plating

R. M. ANGLES: 'Some Practical Aspects of Tin-Nickel Plating.'

Tin and Its Uses, 1959, No. 48, Autumn, pp. 1–4.

Since the announcement in 1951 of the development, in the laboratories of the Tin Research Institute, of a process for electrodeposition of a tin-nickel alloy, such coatings, which for many purposes offer advantages over other metal finishes, have found increasing application in industry: they have, for example, been used for such diverse components as electrical fittings, musical instruments, tea kettles, frying pans, industrial drying equipment, watches and drawing instruments (see, in this connection, abstract in *Nickel Bulletin*, 1959, vol. 32, No. 1, p. 9), and a wide range of equipment exposed to corrosive chemicals. In the present paper the author is concerned with variables of importance in the operation of the tin-nickel plating solution.

After a brief discussion of the properties of tin-nickel deposits (in particular, corrosion-resistance) and of the economic aspects of the process, the author draws attention to the rôle played by the individual constituents of the electrolytes, and outlines the plating conditions and precautions which experience has shown to ensure optimum results. In this connection, the choice of anodes is discussed, and advice is given on methods of filtrating the solution and removing organic and inorganic contaminants.

See also following abstract.

Electrodeposition of Tin-Nickel Coatings

T. T. CAMPBELL and R. ABEL: 'Codeposition of Tin-Nickel Plate from Organic and Mixed Aqueous-Organic Solvents.'

U.S. Bureau of Mines, Report of Investigations 5482, 1959; 11 pp.

Tin-nickel coatings electrodeposited from the fluoride electrolyte (which contains nickel and tin

chlorides, sodium fluoride and ammonium bifluoride) have a corrosion-resistance higher than that of either tin or nickel alone. The electrolyte possesses excellent throwing power, is readily controlled, and operates well over a wide range of concentration and current density. Its main drawbacks are its corrosive nature and the evolution of hydrofluoric-acid fumes during cell operation. The work covered by this report was carried out to explore the feasibility of developing a tin-nickel plating solution less corrosive than the fluoride electrolyte.

The investigation was planned along empirical lines, and the wide variety of aqueous-basic, organic, and mixed-aqueous-organic electrolytes studied are listed in the report. The study revealed the feasibility of depositing, from organic or mixed-aqueous-organic solvents such as formamide, acetamide, triethanolamine, and ethylene-glycol electrolytes, tin-nickel alloys with a nominal composition (60–70 per cent. tin, 30–40 per cent. nickel) and structure approximating closely to that of deposits obtained from the commercially accepted aqueous-fluoride bath. The compositions of, and the results obtained with, these electrolytes form the main subjects of the report.

The nickel-tin alloys deposited from the acetamide and the triethanolamine/hydrochloric-acid solutions appeared to be less highly stressed than those obtained from the fluoride solution: a result which is attributed to the fact that the deposit from the former solutions exhibited random orientation (in contrast to the preferred orientation shown by the nickel-tin alloy deposited from the fluoride electrolyte).

The most promising of the electrolytes studied was the ethylene-glycol/hydrochloric-acid solution (see composition below). Despite wide variations in cathode-current density, total salt concentration, weight ratio of nickel to tin salts, and in ethylene-glycol concentration, bright deposits of constant composition were deposited from this solution over an operating period of three months.

Ethylene glycol	200 ml.
Water (distilled)	400 ml.
HCl (concentrated)	500 ml.
$SnCl_2 . 2 H_2O$	120 g.
$NiCl_2 . 6 H_2O$	300 g.

Nickel Immersion Plating of 'Zircaloy-2'

L. R. KOHAN: 'Immersion Plating on 'Zircaloy-2'.'
Metal Finishing, 1959, vol. 57, Nov., pp. 68–73.

The object of the test programme was to develop a process capable of depositing a uniform coating of a desired metal on the zirconium-base alloy 'Zircaloy-2'. Electroplating was rejected since the thickness of the coating produced would be expected to vary considerably over large flat sections. Immersion plating, if feasible, would, however, provide a method of obtaining a uniform coating of a thickness easily controllable to the design tolerance of $\pm 0{\cdot}03$ mil, and was therefore selected for study in the work described.

Deposition of four metals was studied: copper, iron, tin and nickel. Solutions and plating procedures eventually developed for each are recorded in the paper, and details are given of the experimental work involved. Using the solutions and conditions listed below, deposition of nickel progressed rapidly during the first few minutes of plating, but the rate of deposition decreased considerably after 20 minutes, and after approximately 40 minutes was virtually nil.

$NiCl_2 \cdot 6H_2O$	50 gm.
$CH_3COONa \cdot 3H_2O$ (sodium acetate)	10 gm.
HF (48 per cent.)	4·0 ml.
H_2O	1·0 L.

Temperature—Boiling (to provide both agitation and constant temperature)
Time 35 minutes
pH 4–5

Investigation of the uniformity of the nickel coating so produced showed that the variation in thickness was never greater than $\pm 0{\cdot}03$ mil., and was, in most cases, less.

One-Coat Enamelling of Steel

'A Major Break-Through in White 'Direct-On' Porcelain Enamelling.'
International Enamellist, 1959, vol. 9, No. 4, pp. 20–2.

The article gives details of a porcelain-enamelling procedure, developed by Hanson Porcelain Enamel, Inc., Boston, which eliminates the need for a ground coat, and, involving only one firing stage, enables the production, on cold-rolled rim steel, of porcelain enamel of cover-coat quality.

The success of the process, which is claimed to produce a coating of improved texture exhibiting higher impact-resistance, torsion-resistance and adherence, is due, in great part, to the rigid control exercised in preparation of the basis metal. The steel is boiled clean, rinsed, dried, annealed at 1200°F. (650°C.), pickled in hot phosphoric acid, rinsed, and finally coated with nickel to achieve a deposit of 0·05–0·09 gm./sq. ft. The component is then sprayed and fired. Due to the formation of a corrosion-resistant nickel-oxide layer, in many applications only one side of the component need be enamelled.

The article includes details of the equipment and metal-preparation and enamelling procedures used.

NON-FERROUS ALLOYS

Machinable High-Density Tungsten-Nickel-Copper Alloys: Specification

AMER. SOC. TESTING MATERIALS: 'Tentative Specification for Machinable High-Density Tungsten-Nickel-Copper Alloys.'
A.S.T.M. Designation B 346–59 *T.*
Supplement to Book of A.S.T.M. Standards, Including Tentatives, Part II, Non-Ferrous Metals, 1959, pp. 149–50.

The machinable high-density alloys to which the specification relates are produced by powder-metallurgical techniques and fall within the following

limits of composition: tungsten 90 ± 1, nickel 6 ± 2, other elements 1·5 max., per cent., remainder copper.

Requirements are laid down with respect to density, hardness, tensile properties, machinability, and methods of determining the first three of these properties.

Wrought Copper-Alloy Wire: Specification

AMER. SOC. TESTING MATERIALS: 'Tentative Specification for General Requirements for Wrought Copper-Alloy Wire.'

A.S.T.M. Designation B250-58a T. Supplement to Book of A.S.T.M. Standards, Including Tentatives, Part II, Non-Ferrous Metals, 1959, pp. 28–35.

The specification covers general requirements common to several wrought-product specifications (which are quoted) relating to the following grades of copper-alloy wire: Copper-Silicon Alloy Wire for General Purposes; Brass Wire; Phosphor-Bronze Wire; Copper-Beryllium Alloy Wire; Copper-Nickel-Zinc (Nickel Silver) Wire.

Particulars are given of manufacture, sampling, testing, dimensions and tolerances.

Influence of Heat-Treatment on the Temperature Coefficient of Resistance of Copper-Nickel Alloy Wire

W. WIEBE: 'The Behaviour of Fine Copper-Nickel Alloy Wires with Negative Temperature Coefficients of Resistance.'

Nat. Research Council of Canada, Report MS-100, Feb. 23, 1959; 9 pp. + figures, tables and appendices.

In some cases, the temperature coefficient of resistance of certain alloys (*inter alia*, the copper-nickel alloy 'Constantan') decreases with increase in temperature. The temperature coefficient of resistance of an alloy is believed to be a function of such variables as strain level, thermal history and heat-treatment, minute changes in alloy composition and variations in trace elements. Experimental work has shown that the initial value of the temperature coefficient of resistance can be changed (in general, towards a positive value) by appropriate heat-treatment, and the work described was conducted with the aim of determining the resistance stability of 'Constantan' wire at various temperatures, and the relationship between the temperature coefficient of resistance and the time of heat-treatment.

Two groups of 'Constantan' wire (known commercially as 'Cupron'), nominally containing copper 55, nickel 45, per cent., were studied. The data recorded indicate that heat-treatment had a pronounced effect upon the electrical resistance and the temperature coefficients of resistance of the wires, and that resistance changed continuously at temperatures higher than 500°F. (260°C.).

The relationships established between time of heat-treatment *in vacuo* at 860°F. (460°C.) and the temperature coefficient of resistance are recorded and discussed. The information obtained is applied to the selection of suitably heat-treated wires for fabrication of experimental temperature-self-compensating strain gauges (for use on aluminium and steel in the range 75°–350°F. (24°–175°C.)). The approach adopted was to compensate for the apparent strain error due to differential thermal linear expansion by selection of an appropriate value of temperature coefficient of resistance for the strain-sensitive wire.

Appended to the report is a brief survey of available information on experimental and commercial strain gauges for use at elevated temperatures, and on alloys and adhesives of interest in this respect.

Anisotropy in the Magneto-Resistance of Nickel-base Alloys

See abstract on p. 9.

Use of Non-Ferrous Materials in Various Industries: Historical Reviews

Metal Industry, 1959, vol. 95, Dec. 4, the Golden Jubilee Issue of the Journal, contains a series of eight articles reviewing developments in non-ferrous metals in various industries during the 50 years since the Journal was first published. Each of the reviews is of basically similar format: the status of the particular industry and the materials used at the beginning of the period covered are outlined, the rôle played by various non-ferrous metals and alloys since that time is discussed, and finally the author comments on future trends. Nickel and nickel-containing materials find application in most of the industries reviewed.

References to the eight articles are given below.

P. L. TEED: 'Non-Ferrous Metals in the Aircraft Industry', pp. 359–63.

S. F. DOREY: 'Non-Ferrous Metals in the Marine Industry', pp. 364–9.

T. H. TURNER: 'Non-Ferrous Metals in the Railway Industry', pp. 370–5.

R. J. BROWN: 'Non-Ferrous Metals in the Automobile Industry', pp. 376–81.

J. B. COTTON: 'Non-Ferrous Metals in the Chemical Industry', pp. 382–7.

E. HARGREAVES: 'Non-Ferrous Metals in the Oil Industry', pp. 388–9.

N. L. HARRIS: 'Non-Ferrous Metals in the Electrical Industry', pp. 390–5.

N. L. BRICE: 'Non-Ferrous Metals—Their Military Application', pp. 396–401.

Induction Brazing and Soldering

See abstract on p. 2.

Welding of Dissimilar Metals by the Metallic-Arc Process

See abstract on p. 32.

Production of Raised Studs on Metal Surfaces by Spot Welding

See abstract on p. 1.

NICKEL-IRON ALLOYS

Review of Modern Ferromagnetic Materials

F. BRAILSFORD: 'Modern Ferromagnetic Materials: An Electrical-Engineering Review.'
Jnl. Inst. Electrical Engineers, 1959, vol. 5, Aug., pp. 417–24.

The review is introduced by a general outline of the more important characteristics of ferromagnetic materials, involving discussion of magnetisation curves, hysteresis, limitations imposed at high frequencies by the high electrical conductivity of ferromagnetic metals, and ferromagnetic domain structures.

The main section of the review is concerned with developments in magnetic materials of practical interest to electrical engineering. Discussed first in this respect are the characteristics of the silicon-iron alloys and the properties offered by grain-oriented types in power-plant applications. Notes on the nickel-iron alloys include references to the range of properties obtainable by variation of nickel content, to the commercial advantage which has been taken of the effects of this variation (e.g., 'Rhometal', 'Radiometal', and 'H.C.R. alloy'), and to the high permeability obtainable in such alloys as 'Permalloy' and 'Mumetal'. A summary of the functions and features of a permanent magnet introduces discussion of the following groups of permanent-magnet materials: martensitic steels, soft-iron powder, ferrites, and the extensively used iron-nickel-aluminium alloys. Throughout the review the magnetic characteristics of the different generic groups covered are exemplified by curves relating to commercially-available materials. Drawings are used to illustrate the influence of grain orientation.

The paper closes with a short discussion of the phenomenon of ferrimagnetism.

Anisotropy in the Magneto-Resistance of Nickel-base Alloys

H. C. VAN ELST: 'The Anisotropy in the Magneto-Resistance of Some Nickel Alloys.'
Physica, 1959, vol. 25, pp. 708–20.

Data are reported on the anisotropy of the electrical magneto-resistance of a series of forty polycrystalline nickel-cobalt, nickel-iron, nickel-iron-copper, nickel-palladium, nickel-chromium, nickel-silicon, nickel-tin, nickel-aluminium, nickel-vanadium, nickel-manganese, nickel-tungsten, and nickel-molybdenum alloys. The measurements were carried out, in magnetic fields up to 20 kOe, at 293°, 77°, 64°, 20° and 14°K. (20°, −196°, −209°, −253°, −259°C.). The magnetic field was applied parallel as well as transverse to the measuring current of the resistance.

The data tabulated on the resistance anisotropy and magnetic field coefficients of the alloys are discussed in the light of the various theories proposed by previous workers in explanation of the phenomena involved.

Hard Magnetic Materials

E. P. WOHLFARTH: 'Hard Magnetic Materials.'
Advances in Physics, 1959, vol. 8, Apr., pp. 88–224.

In introducing the review the author defines hard magnetic materials as 'substances with a high coercive force, say, about 100 Oersted', and goes on to comment: 'If such materials also possess high remanent magnetisation they have innumerable uses as permanent-magnet materials. For this reason, an enormous body of experimental and theoretical research has grown up, and many spectacular advances have been made over the last 30 years or so, not least in the very recent past. It seems not unlikely that the immediate future will see a consolidation of this state of affairs rather than a continuation of rapid progress. For this reason a review of past achievement may not be inappropriate at this time, and such a review is presented in what follows.'

The review, in which reference is made to a *bibliography* of 400 items of literature, is in seven sections. In the first the author outlines the theories advanced in explanation of the properties and magnetic phenomena associated with hard magnetic materials. The second, which summarises experimental work carried out on metallic powders (including iron, cobalt, nickel and their alloys), is followed by a survey of research on the properties of iron oxide and related powder materials. The magnetically hard ferrites (cobalt and barium ferrites) are considered in section four, while, in section five, ferromagnetism and superparamagnetism are discussed in relation to work on binary alloys containing a small amount of the ferromagnetic component. The development and properties of 'Alnico'-type alloys form the subjects of section six, and the review ends with a discussion of literature reporting work on copper-iron-nickel, copper-nickel-cobalt, iron-cobalt-tungsten, iron-cobalt-molybdenum, iron-molybdenum-tungsten, iron-molybdenum, iron-cobalt-vanadium, iron-platinum, and cobalt-platinum permanent-magnet alloys.

Developments in Soft Magnetic Materials

E. W. LEE and A. C. LYNCH: 'Soft Magnetic Materials.'
Advances in Physics, 1959, vol. 8, July, pp. 292–348.

Considerable advances have been made in the development of soft magnetic materials since the end of the last war. The state of development obtaining in 1950 is described in BOZORTH's book 'Ferromagnetism', published in 1951, which contains a comprehensive account of the materials and their properties. In the present review, which is based on a *bibliography* of 172 items and which includes a comprehensive survey of the theoretical factors relevant to properties and performance, the authors take this book as a starting point and concentrate mainly on developments since its publication.

These developments are discussed in sections relating to: preparation and fabrication of soft magnetic

alloys; methods of investigating magnetic characteristics; new magnetic materials (iron-aluminium, iron-cobalt and silicon-iron alloys; nickel-iron-alloy films deposited by evaporation); characteristics of soft magnetic materials; the 'Permalloy problem' (i.e., the problem of explaining the characteristic magnetic properties possessed by binary nickel-iron alloys containing a minimum of 35 per cent. nickel); magnetic annealing and related topics; ferrimagnetism and ferrites; and frequency dependence of magnetic permeability and related topics.

Long-Term Stability of Permanent-Magnet Materials

K. J. KRONENBERG and M. A. BOHLMANN: 'Long-Term Magnetic Stability of 'Alnico V' and Other Permanent-Magnet Materials.'

Wright Air Development Centre, Tech. Report 58-535, Dec. 1958; 47 pp.

The report gives details of an investigation in which variations in the remanence (Bd) of permanent-magnet materials representative of those in commercial use were determined over periods of up to $2\frac{1}{2}$ years.

Five materials were selected for study: the iron-nickel-aluminium alloy 'Alnico III'; the iron-cobalt-nickel-aluminium alloys 'Alnico V' and 'Alnico VII'; and the barium ferrites 'Indox I' and 'Indox V'. 'Alnico V' was the subject of extensive study.

To investigate the influence of shape on magnetic stability, the magnets, straight bars from commercial production, were manufactured in groups of varying lengths. During the test programme all the magnets investigated were separately stored (at a temperature of $24° \pm 2{\cdot}5°C.$) in a room free from interference by other magnetic substances. After magnetisation the remanence of each magnet was carefully measured at regular intervals, using precision equipment, based on an impulse-compensation principle, which permitted measurements to be made to an overall tolerance of less than 1 in 10,000. The materials, measuring equipment and procedures, and the magnetisation process and stabilising methods employed are described in detail. The data obtained are summarised in the form of graphs.

For most applications (i.e., where the tolerances are in the region of 3 per cent. or above) magnets fabricated from 'Alnico' and 'Indox' are considered stable: a year after magnetisation the remanence of a few of the 'Alnico V' magnets was at least 99·9 per cent. of the initial value. When some time had elapsed after magnetisation, most of the magnets were, however, found to have slightly lower remanences, and in an extreme case remanence had decreased to 97 per cent. of the initial value. For applications demanding the highest degree of stability, magnets must therefore be artificially stabilised, and two types of stabilising treatment were evaluated in the present study: temperature cycling, and exposure to 60 cps. a.-c. fields. Temperature cycling between room temperature and $-65°C.$ proved more effective than cycling at high temperatures (100°, 350° or 505°C.), and at 350° and 505°C. slight permanent changes were observed in 'Alnico V'. Of the two stabilising methods, the more effective was that in which remanence was reduced by about 10 per cent. during exposure to an a.-c. demagnetising field. The remanences of stabilised magnets were found to be completely stable within the limits of accuracy of the measuring equipment.

From the data obtained within the restrictions imposed by the experimental conditions investigated, the authors draw the following generalisations:

'(1) The higher the coercive force, the more stable is the remanence. Of the five materials studied, 'Indox I', having the highest Hci, was most stable. Measurements of its remanence indicate no changes at room temperature after more than a year. 'Alnico III' has the lowest coercive force and was least stable. In the worst cases, remanences were still 97 per cent. of their original values 10,000 hours after magnetisation.

'(2) The greater the shape ratio of a magnet, the more stable is its remanence. This is true for each material studied: for example, when 'Alnico V' is shaped into a magnet of suitable length ($L/D = 8{\cdot}7$), no losses in remanence can be detected over a long time.

'(3) Remanence of a magnet decreases linearly with the logarithm of time when a magnet lies undisturbed at room temperature. This relation is expected to hold for all permanent magnets of any material which does not change in time.

'(4) Remanence of a magnet can be stabilised by reducing Bd artificially. This we did by two different methods: temperature cycling or applied a.-c. fields. When properly stabilised, remanence has stayed stable for one year and very likely will remain so. This stability was determined to $\pm 0{\cdot}01$ per cent.

'(5) Remanences were completely stabilised by reducing them 5–15 per cent. by either of the two stabilising methods. In several exceptions, stability was achieved with smaller or larger knockdowns (over 35 per cent.) but usually the remanence behaved erratically.

'(6) The remanences of incompletely magnetised magnets are more stable than those of fully magnetised. Since we magnetised each magnet with saturating fields, our stability curves show the *maximum* losses which may be encountered. However, incompletely magnetised magnets are still not as stable as remanences artificially stabilised.'

The report includes a review of Neel's theory on stability in permanent magnets, and it is pointed out that the term 'ageing' is correctly used only when applied to describe the behaviour of magnets (such as steel) undergoing permanent changes with time. The term is inappropriate used in relation to 'Alnico' or barium ferrite, since these materials are unchanged at room temperature. Work in connection with the project described is continuing, and problems yet to be investigated are referred to in the report.

CAST IRON

Properties and Applications of 'Ni-Hard'

R. B. WHITELAW: ' 'Ni-Hard' versus Abrasion.'
Inst. Brit. Foundrymen (Australian Branch), 1959, vol. 10, pp. 57–75.

The world output of nickel is now sufficient to meet all demands, and the ready availability of the metal has stimulated basic research on, and widened the range of applications of, most nickel-containing materials. The present paper is concerned with research and development work on the abrasion-resistant nickel-chromium white cast iron 'Ni-Hard'.

The structural features of the iron are briefly outlined and attention is then directed to factors influencing its excellent abrasion-resistance under dry-grinding conditions. The composition of 'Ni-Hard' and the compositional modifications necessitated by service requirements, casting conditions and casting section are commented upon, and reference is made to work on suitable heat-treatments. Brief notes are given on casting procedures, and the physical and mechanical properties of sand-cast and chill-cast regular and high-strength grades of the iron are summarised.

Emphasis is placed in the review on applications exemplifying those which 'Ni-Hard' finds in the metal-working, mining, cement, ceramic and other industries. In this connection, details are given of service experience with, *inter alia*, rolls, mill-liners, grinding balls and silpebs cast in 'Ni-Hard'.

Determination of Nickel in Cast Iron

See abstract on p. 5.

CONSTRUCTIONAL STEELS

Summary of British and Foreign Specifications for Steel Castings

See abstract on p. 1.

Simultaneous Spectrophotometric Determination of Copper and Nickel in Low-Alloy Steels.

M. FREEGARDE and B. JONES: 'The Simultaneous Spectrophotometric Determination of Copper and Nickel in Low-Alloy Steels'.
Analyst, 1959, vol. 84, Dec., pp. 716–9.

Details are given in the paper of a simple spectrophotometric procedure for simultaneous determination, in low-alloy steels, of copper and nickel present in amounts up to 1 per cent. Bis*cyclo*hexanone oxalyldihydrazone is used as a colorimetric agent for copper, and disodium ethylbis(5-tetrazolylazo)acetate for nickel. A single sample can be analysed in 20 minutes.

The steel is dissolved, the solution is buffered, and solutions of the two reagents are then added. The optical density of the resulting solution is measured on two wavelengths, and the amounts of copper and nickel present are determined by reference to a calibration graph. Four British Chemical Standard low-alloy steels have been analysed using the procedure: the data presented in this connection show a coefficient of variation of approximately 2 per cent.

Fatigue Properties of Notched Steel Specimens

S. YUKAWA and J. G. McMULLIN: 'High-Stress, Low-Cycle Fatigue Properties of Notched Alloy-Steel Specimens.'
Bull. Amer. Soc. Testing Materials, 1959, Oct., pp. 38–40.

The experiments reported were carried out to obtain data on the effects of repeated high stress on severely notched components.

Three types of specimen were used in the investigation: a small double-notched plate specimen, a large notched plate specimen, and a notched bend bar. The specimens were cut from a large forging in steel of the following composition: carbon 0·24, sulphur 0·023, phosphorus 0·026, nickel 2·92, molybdenum 0·55, vanadium 0·07, per cent. Using the small double-notched specimens with a zero stress ratio, S–N curves were first determined up to 10,000 tension cycles. Identical specimens were then subjected to stress levels corresponding to fatigue lives in the range 500–5,000 cycles. At various stages of their fatigue life single-cycle overloads of from 10 to 40 per cent. above the cyclic stress were applied, and the tests were then continued to failure at the original stress level. Tests (also with zero stress ratio) were carried out on the large notched plate specimens in the as-received and 'notch-ductile' conditions. The bend specimens were evaluated in tests involving three-point bending with the notched side in tension.

The results presented disclosed three trends. Firstly, it appeared that 10^4 loading cycles can produce failure at a nominal stress level only 50 per cent. as great as the static strength of the specimens. Secondly, it was found that the final brittle fracture could initiate suddenly after very little growth of a fatigue crack. Lastly, the 10 per cent. and 20 per cent. single overloads to which the thin double-notched specimens were subjected during testing tended to increase the fatigue life of the few specimen so tested.

Influence of Microstructure on Notch-Toughness of Steels

E. H. KOTTCAMP and R. D. STOUT: 'Effect of Microstructure on Notch-Toughness. Part IV.'
Welding Jnl., 1959, vol. 38, Nov., pp. 435s–40s.

The present paper is one of a series reporting the results of work carried out to determine the effect of microstructural and compositional variables on the notch-toughness of low-carbon steels used for welded structures. Previous investigations having indicated that the ferrite phase plays an important rôle in determining the notch-toughness of such materials, the investigation now described was initiated in an attempt to obtain a better understanding of this relationship.

The tests were conducted on five aluminium-killed ferrites (plain-carbon, nickel, molybdenum, manganese and chromium) selected for study as approximating to the ferrite present in commercially available steels.

In the first phase of the investigation Charpy V-notch impact tests were conducted to evaluate the influence of the following variables on the transition temperatures of the ferrites: grain-size, alloying elements, sub-critical heat-treatments used in stress-relieving. Experiments were carried out also to locate the region or regions of the microstructure responsible for initiation of brittle-cleavage failure.

The notch-toughness of the ferrites was found to vary considerably with the heat-treating cycles employed, and, in an effort to relate the observed behaviour to any microstructural changes which may have occurred, an intensive metallographic investigation was carried out in the second phase of the test programme. Particular attention was paid to the effects of substructure and precipitation within the grains and at the boundaries.

Full details are given of the test conditions, and the data presented are supplemented by photomicrographs illustrating the findings of the metallographic studies. The authors' summary of the results is quoted below.

'1. The notch-toughness of ferrite, which is the predominant phase in structural steels, was controlled primarily by its grain-size. However, grain-size was not the only important microstructural variable.

'2. In the absence of alloying elements, ferrite was embrittled by furnace cooling through the temperature range below transformation. This was true whether cooling followed austenitising or a reheating treatment below transformation. Holding the ferrite at 1300°F. (705°C.) for 96 hr. eliminated this embrittlement regardless of subsequent cooling.

'3. Manganese and nickel increased the toughness of ferrite largely by refining the ferrite grain-size. The effect of chromium was generally weaker in this respect, while molybdenum was ineffective.

'4. Nickel and molybdenum had no effect on the subcritical embrittlement observed in the alloy-free ferrite. Manganese appeared to suppress this embrittlement. Chromium retarded the changes in toughness resulting from subcritical treatments but did not affect the embrittlement produced by furnace cooling from the austenitising temperature.

'5. Careful examination of the microstructural details, using the optical and electron microscopes, did not reveal changes in the microstructure which could be associated with the subcritical embrittlement. The presence of substructure and precipitates was given special consideration.

'6. Observation of microcrack initiation supported the results reported previously for ferrite-pearlite aggregates, i.e., cleavage cracks originated at ferrite-grain boundaries and possibly at mechanical twins. While cracking was normally transcrystalline, those specimens which were subcritically embrittled exhibited some intergranular cracking.'

Influence of Phosphorus and Sulphur on the Ductility and Impact-Resistance of Cast Steels

J. ZOTOS: 'Cast Low-Alloy Steels: Ductility and Toughness.'

Modern Castings, 1959, vol. 36, Nov., pp. 698–701.

The experiments described were carried out during work on the development of a melting practice suitable for the production of low-phosphorus and low-sulphur steel in a 9-ft.-diameter basic electric-arc melting furnace.

The melting practice ultimately evolved, details of which are given in an appendix to the paper, enabled the sulphur and phosphorus contents to be decreased to the region of 0·01 per cent. (The influence of the processing time on sulphur and phosphorus contents is discussed in relation to carbon steel (A.I.S.I. 1040), low-alloy chromium-molybdenum steel (4140) and nickel-chromium-molybdenum steels (4325, 4330 and 4340).) To determine the effect of this decrease on the mechanical properties of the steel, tests were made on castings in A.I.S.I. 4325 and 4340 nickel-chromium-molybdenum steels which had been subjected to various heat-treatments. Tensile strength, yield strength (0·1 per cent. offset), elongation, and reduction-in-area were determined at room temperature, and Charpy V-notch impact tests were conducted at −20°F. (−29°C.).

The decrease in the sulphur content of the 4325 castings (the two heats of which steel contained 2·45 and 2·3 per cent. of nickel, respectively) resulted in a significant increase in reduction-in-area, impact-strength and elongation, the strength properties remaining constant. Lowering both the phosphorus and sulphur contents of 4325 and 4330 castings also resulted in a considerable improvement in ductility and impact-resistance.

Influence of Trace Elements on Isothermal Embrittlement in Nickel-Alloy Steels

W. STEVEN and K. BALAJIVA: 'The Influence of Minor Elements on the Isothermal Embrittlement of Steels.'

Jnl. Iron and Steel Inst., 1959, vol. 193, Oct., pp. 141–7.

In the first stage of the programme of research to which the work described relates it was shown that high-purity steels are not susceptible to isothermal embrittlement (see BALAJIVA, COOK and WORN, *Nature*, 1956, vol. 178, p. 433: abstract in *Nickel Bulletin*, 1956, vol. 29, No. 10–11, p. 191). The present paper is concerned with a further study of the immunity to embrittlement shown by high-purity steels, and with the effects, on this immunity, of the presence of controlled amounts of various elements. In the final section of the paper some attention is given to the fracture habits of some of the steels.

High-purity steels of nominal composition carbon 0·3, nickel 3, chromium 0·75, per cent., and in some cases containing also 0·5 per cent. of molybdenum, were prepared by vacuum melting, and the influence, on susceptibility to isothermal embrittlement, of individual trace additions of the following elements was

determined: manganese, silicon, phosphorus, antimony, arsenic, tin, bismuth, cobalt, copper, germanium, gallium, zirconium and nitrogen. The steels were forged and rolled to bar and heat-treated as blanks. Each steel was fully hardened, tempered and water quenched from the tempering temperature. The embrittling treatment employed consisted in reheating the hardened-and-tempered steels at 450°C. for 168 or 1000 hours and water-quenching. The impact-transition range of each steel, before and after exposure at 450°C., was determined, using standard Charpy V-notch specimens, by two criteria: the temperature at which fracture was 50 per cent. fibrous, and the lowest temperature at which the fracture was wholly fibrous.

It is considered that the results obtained have established the qualitative effects of the impurities studied: quantitative effects will vary with the temperature at which embrittlement is induced, and may be dependent also on the microstructure of the steel and on the proportions of the normal alloying elements present. The study was, moreover, confined to assessing the separate effects of individual impurities, and it cannot be assumed that the effect of two or more of the elements in combination will be simply additive. Within these limitations the authors consider that the following conclusions are justified:

'1. A steel containing carbon, nickel, chromium and molybdenum, but substantially free of trace elements, is not susceptible to embrittlement within 1000 hours at 450°C.

'2. The presence of phosphorus, antimony, arsenic, tin, manganese, or silicon promotes susceptibility to embrittlement at 450°C. The most potent of these elements is antimony. The presence of small percentages of bismuth, cobalt, copper, germanium, gallium, zirconium, or nitrogen, at least up to the levels studied in this investigation, does not induce susceptibility to embrittlement at 450°C.

'3. Molybdenum retards, but does not prevent, development of embrittlement.

'4. The brittle fractures of steels susceptible to embrittlement are substantially intergranular.'

Influence of Nickel Content on the M_s Temperature of Nickel-Alloy Steels

C. A. CLARK: 'The Dependence of M_s Temperature on Nickel Content in Nickel-Alloy Steels.'

Jnl. Iron and Steel Inst., 1959, vol. 193, Sept., pp. 11-12.

The main object of the work described was to obtain a general equation relating the temperature of formation of martensite to the nickel content of nickel-alloy steels. From a review of the relevant literature it became clear that there was some discrepancy between M_s temperatures for low-alloy steels as reported, for example, by STEVEN and HAYNES (see abstract in *Nickel Bulletin*, 1956, vol. 29, No. 8-9, p. 166) and values obtained for pure iron-nickel alloys by KAUFMAN and COHEN (see abstract in *Nickel Bulletin*, 1957, vol. 30, No. 1-2, pp. 7-8). According to Haynes it is possible that Kaufman and Cohen actually observed the onset of bainite transformation, rather than the M_s temperature, for alloys containing less than about 18 per cent. nickel, and it was therefore decided to include in the analysis the results given by Steven and Haynes, and those reported by Kaufman and Cohen for alloys containing more than 18 wt. per cent. of nickel. These data were supplemented by those gained by the present author on a number of iron-carbon-nickel alloys using standard dilatometric techniques. The results subjected to the statistical analysis described were therefore obtained from more than one hundred steels containing up to 34 wt. per cent. nickel.

It is shown that the dependence of the M_s temperature on the nickel content may be represented by the equation

$$M_s^2 = 70{\cdot}1 \times 10^4 - 2{\cdot}90 \times 10^4 Ni + 2{\cdot}60 \times 10^2 Ni^2.$$

Development of a Non-Embrittling Cadmium-Plating Process for High-Strength Steels

P. N. VLANNES, S. W. STRAUSS and B. F. BROWN: 'Progress Toward the Development of a Non-Embrittling Cadmium Electroplating Process. III. The Use of Triethanolamine in Cadmium-Plating Solutions.'

Plating, 1959, vol. 46, Oct., pp. 1153-7.

In continuation of research to develop a cadmium-plating process which would not cause embrittlement when used to plate ultra-high-strength nickel-chromium-molybdenum steel (A.I.S.I. 4340), a study was made of the plating characteristics of non-cyanide solutions containing triethanolamine (TEA) or triethanolamine plus glycine (TEAG), with and without additives. (An abstract of part II of the series will be found in *Nickel Bulletin*, 1959, vol. 32, No. 11, p. 327.)

Satisfactory deposits were obtained from solutions at a cadmium concentration of 1 M/litre, the concentration of TEA being set at 1·26-1·51 M/litre for proper control of the solution. In the case of the TEAG solution, optimum plating conditions were obtained at a concentration of 0·15 M/litre of glycine. Continuous plating, using a horizontal plating barrel, showed that it was possible to plate from the TEA and TEAG solutions 24 hours a day for 30 days, and that the only maintenance required was to renew the cadmium anodes and to ensure a constant volume of liquid by periodic additions of distilled water.

Results of delayed-fracture tests on plated notched specimens of A.I.S.I. 4340 nickel-chromium-molybdenum steel heat-treated to ultra-high-strength levels indicated that under controlled-current-density conditions the TEA solution was non-embrittling.

'Thermomagnadynamics': New Heat-Treatment for High-Strength Steels

F. G. MCGUIRE: 'Breakthrough in Heat-Treating Promises Huge Gains in Strength.'

Missiles and Rockets, 1959, Sept. 28, pp. 10-11.

The article reviews, in general terms, the scope of

a heat-treatment process developed by Research Development Corporation of America. The treatment, termed 'Thermomagnadynamics', and which is now the subject of patent proceedings, is claimed to achieve increases in ultimate tensile strength of up to 60 per cent., associated with corresponding improvements in ductility, fatigue-strength and impact-resistance. Heat-treated materials having a hardness up to R_c 62 can be bent at least 100° without fracture.

Discovered by W. I. BASSETT, the process rearranges the metallic grain into an isotropic granular structure during heat-treatment and after fabrication. The homogeneous ultra-fine grain structure minimises notch-sensitivity and, under load, the stress is apparently evenly distributed throughout the structure.

The article includes data typifying the ultimate tensile strength, elongation and reduction-in-area obtainable by the 'Thermomagnadynamic' process in low-alloy chromium-molybdenum, nickel-chromium-molybdenum, and chromium-vanadium steels, and in martensitic stainless steels. A.I.S.I. Type 4340 nickel-chromium-molybdenum steel has, for example, an ultimate tensile strength of 335,000 p.s.i. (150 t.s.i.; 235 kg./mm.^{2}), an elongation of 11 per cent. and a reduction-in-area of 28 per cent., while the corresponding values for 'A-286' precipitation-hardenable stainless steel are 174,000 p.s.i. (76 t.s.i.; 122 kg./mm.^{2}), 25 per cent. and 55 per cent.

Case-Hardening of Nickel-Alloy Steels

MOND NICKEL CO., LTD.: 'The Case-Hardening of Nickel-Alloy Steels.'

Publn. 1650*, 1959; 36 pp.

Nickel-alloy carburising steels are widely used for case-hardened parts, and have a long record of successful application in industry. They respond readily to normal case-hardening practice, provide cases exhibiting high resistance to wear and fatigue, and are particularly suitable for heavy and arduous duty. They also have the great advantage of responding satisfactorily to, and providing good properties after, a simplified final heat-treatment. This publication outlines the metallurgical factors involved in, and describes the various carburising methods available for, case-hardening such steels.

In the introduction to the review reference is made to the history and aims of case-hardening, and the types of steel used are briefly discussed. A *résumé* of the metallurgical factors associated with case-hardening is followed by sections describing the equipment and procedures used in the three processes available (pack carburising, gas carburising and liquid carburising). Ways of achieving selective carburising are briefly alluded to and information on heat-treatment of the steel after carburising, which is discussed in some detail, includes data illustrating the effects of sub-zero treatment and of tempering on case hardness.

A section on carburising defects is followed by notes on grinding case-hardened steels and by a summary, supplemented by data on the relevant properties, of the factors influencing core properties and the fatigue-strength of carburised nickel-alloy steels. In the last section a list is given of the types of nickel case-hardening steels available.

Appendices contain a list of U.S.A. case-hardening steels and notes and data on the relationship between case depth and the temperature and time of carburising.

* *We shall be pleased to supply a free copy of this publication.*

Machining of Nickel-containing Ultra-High-Strength Steels

J. MARANCHIK, J. V. GOULD and P. R. ARZT: 'Ultra-High-Strength Alloys. Part I: Machining Tests Using High-Speed Steels and Tungsten-Carbide Tooling. Part II: Analysis of Machining Tests on Representative American Materials.'

Aircraft Production, 1959, vol. 21, Nov., pp. 402-9; Dec., pp. 429-33.

Although the use of ultra-high-strength steels for aeronautical applications has increased steadily in recent years, relatively little data are available on their machining characteristics. The investigation now described was initiated to obtain information relevant to the more commonly used materials.

The following steels (representative of the generic groups in parenthesis) were studied: A.I.S.I. 4340 nickel-chromium-molybdenum steel quenched-and-tempered to hardnesses in the range 50-55 Rc (low-alloy martensitic steel); 'Vasco Jet 1000' quenched-and-tempered to the same hardness range (hot-work die steel); the chromium-nickel 'AM-350' steel and the nickel-chromium 'A-286' steel, both in the solution-treated-and-aged condition (representative, respectively, of martensitic and austenitic precipitation-hardenable stainless steels).

Part I of the paper presents the results of turning, face-milling, end-milling and side-milling tests involving investigation of the relationships between tool life, tool geometry, tool material, cutting speeds and feeds. Part II is concerned with an assessment of the data obtained from slot-milling, drilling and tapping tests on materials in different conditions of hardness. (The data presented for the two precipitation-hardenable steels relate only to the turning and drilling tests.)

The information derived during the investigation is summarised in tables listing (for carbide and high-speed-steel tools) the tool geometry, cutter, depth and width of cut, feed, cutting speed, tool life, wear-land and coolant for use in turning, face-, side-, slot- and end-milling, drilling and tapping.

Welding of Dissimilar Metals by the Metallic-Arc Process

See abstract on p. 32.

Induction Brazing and Soldering

See abstract on p. 2.

HEAT- AND CORROSION-RESISTING MATERIALS

Solid-State Reactions in Nickel-base High-Temperature Alloys

J. F. RADAVICH: 'Studies of Solid-State Reactions in High-Temperature Alloy Systems.'

U.S. Atomic Energy Commission, Report APEX 483, Oct. 29, 1958; 17 pp.

The aim of the test programme reported was two-fold: (1) to study the microstructure of an air-melted nickel-chromium alloy, of modified 80-20 type, in the as-received and heat-treated conditions; (2) to study the microstructure and oxidation characteristics of experimental vacuum-melted nickel-base alloys in the as-received and heat-treated conditions.

The composition of the air-melted alloy was as follows: chromium 19·54, niobium 1·27, silicon 0·86, carbon 0·038, zirconium <0·1, boron <0·002, sulphur 0·004, per cent., remainder nickel. The compositions of the three vacuum-melted alloys studied fell within the range: chromium 15·13–16·15, silicon 1·21–1·9, niobium 0·29–0·51, carbon 0·1–0·16, zirconium 0·08–0·13, boron 0·005–0·007, sulphur 0·004–0·006, per cent., remainder nickel. Each alloy was heat-treated for 1, 20 and 100 hours at 1800°F. (980°C.), and was then examined by optical and electron microscopy. The precipitates present were chemically isolated and studied.

The salient findings of the investigation are summarised below.

Air-Melted Alloy

In the as-received condition the alloy was found to contain occasional stringers of carbides which persisted even after 100-hour treatment at 1800°F. (980°C.). Inter- and intragranular precipitation occurred after this treatment, and the number and size of the particles increased with holding time. The shape of the particles varied and included the following forms: oval, square, ribbon and rod. Structural studies showed the particles to consist mainly of niobium carbide, though they also contained chromium, nickel and zirconium.

Vacuum-Melted Alloys

Examination of the alloys in the as-received condition revealed the presence of no discernible amount of precipitated phase. The heat-treated specimens exhibited an oxide scale (Cr_2O_3), the amount of which was found to be inversely proportional to the silicon content. Examination of the alloys near the metal/oxide interface revealed evidence of a layer (presumably of high silicon content) which diminished in thickness with decrease in the silicon content of the alloy. Precipitation within the alloy was related to the niobium content, i.e., the higher the niobium content the greater was the degree of precipitation within the grains and at grain boundaries. No apparent change in the degree of precipitation occurred as the time of heat-treatment was increased, but the two alloys of higher niobium content exhibited fine precipitation throughout the grain. Attempts to isolate the precipitated phases were unsuccessful due to the very small amount of precipitation present, but replication studies of the surface showed that, after etching, the very small precipitates exhibited contours similar to those observed on niobium-carbide particles in other high-temperature alloys.

Reactions Involved in the Oxidation of Alloys

C. WAGNER: 'Types of Reaction Involved in the Oxidation of Alloys.'

Zeitsch. f. Elektrochemie, 1959, vol. 63, Oct., pp. 772–82.

In the preamble to the paper the author draws attention to the complexity of the mechanisms associated with oxidation of alloys, and refers to the following as the characteristic features which distinguish oxidation reactions in alloys from those in metals: (1) In general, the constituents of an alloy will vary in their affinities for oxygen, and the mobility of their actions in the oxide layer will also differ. In many cases, therefore, some regions of the oxide layer and of the adjoining alloy will be enriched with certain of the alloying elements. (2) In contrast to the relationships obtaining during oxidation of a pure metal, the oxide film on an alloy may consist of several layers, each containing two or more phases (for example, a mixture of the nobler metal and of the oxide of the less noble constituent, or, as in the case of the copper-nickel alloys, of two oxide phases).

The evidence available demonstrates the impracticability of developing an interpretation of alloy oxidation which would take into account the wide range of variables involved. In this review (in which reference is made to a *bibliography* of 53 items) the author's aim is therefore to outline, as limiting cases, oxidation reactions, typical of certain alloy systems, in which a quantitative analysis can be made of the diffusion reactions of the individual constituents of the phases present.

The review is in four sections. The first is concerned with the oxidation mechanisms of noble-metal alloys (e.g., nickel-platinum, copper-gold and gold-base alloys); the second with the oxidation of alloys, the constituents of which form simple oxides exhibiting little intersolubility (e.g., copper-nickel, copper-aluminium, copper-beryllium, and copper-zinc); the third with the formation of solid-solution oxides (cobalt-nickel alloys are discussed); and the fourth with the formation of duplex oxides.

Oxidation Characteristics of Nickel-Chromium Alloys

E. A. GULBRANSEN and K. F. ANDREW: 'Oxidation Studies on the Nickel-Chromium and Nickel-Chromium-Aluminium Heater Alloys.'

Jnl. Electrochemical Soc., 1959, vol. 106, Nov., pp. 941–8.

The addition of silicon and small amounts of such

elements as calcium, zirconium and cerium to nickel-chromium heat-resisting alloys of 80-20 type has considerably increased their service life at high temperatures. Various investigations have been conducted in an attempt to throw light on the chemical and physical factors responsible for this improvement in performance (references to abstracts of papers reporting previous work by GULBRANSEN *et al.* will be found in *Nickel Bulletin*, 1954, vol. 27, No. 6, pp. 114-5). The present investigation was conducted on six alloys: five of 80-20 type, and the sixth containing nickel 75, chromium 19, aluminium 4, per cent. The silicon and manganese contents of the five nickel-chromium alloys was varied between 0·23 and 2·09 and 0·02 and 2·3 per cent., respectively.

The aim of the investigation was threefold: (1) to determine, by kinetic studies, the rate of oxidation as a function of temperatures in the range 500°-1100°C.; (2) to evaluate the adherence of the surface oxide film by means of strain-oxidation studies (i.e., by determining the effect of strain on the rate of oxidation of the alloy); (3) to determine the crystal structure and composition of the oxide scale. An oxygen pressure of 7·6 cm. of mercury was used in the experiments, and measurements were made by the vacuum microbalance method. The overall performance of the alloys was assessed on the basis of the A.S.T.M. useful-life tests.

The kinetic studies showed that an alloy with low silicon and manganese contents oxidised at a lower rate than one containing 2 per cent. silicon. No correlation was found between the results of A.S.T.M. life tests and the rate of oxidation of the alloys. In application of the kinetic data to the parabolic rate law, reasonable agreement was found, although a number of deviations were observed. In all the experiments the initial parabolic-rate-law constant was greater than the final value established for thicker films, a variation which is attributed to the occurrence of chemical transitions in the oxide films. Parabolic rate-law data plotted logarithmically as a function of $1/T$ showed two or three straight lines.

The data obtained from the strain-oxidation studies showed good agreement with the results of A.S.T.M. life tests, suggesting that the resistance of the oxide/metal interface to stresses or strain is the most important factor governing the practical performance of the alloys. Silicon and other minor addition elements appear to contribute to the alloys' resistance to the effects of stresses or strains at the oxide/metal interface.

In X-ray-diffraction studies of the crystal structure of the 80-20 nickel-chromium alloys, Cr_2O_3 and $NiO.Cr_2O_3$ spinel were found to be the principal oxides formed, while, in the case of the 75-19-4 nickel-chromium-aluminium alloy, α-Al_2O_3 was also present at 800° and 1000°C., but not at 1100°C.

Orientation relationships are discussed.

Influence of Chromium Diffusion on the Oxidation of Nickel-base Alloys

R. L. SAMUEL and T. P. HOAR: 'The Influence of Chromium Diffusion upon the Thermal Oxidation Properties of Steel and of Nickel- and Cobalt-base Alloys.' *Metallurgia*, 1959, vol. 60, Sept., pp. 75-80.

As exemplified by the chromium-nickel stainless steels and chromium-containing cobalt- and nickel-base alloys, the addition of substantial amounts of chromium to iron, nickel or cobalt considerably increases resistance to thermal oxidation. Since thermal oxidation is a surface reaction, enrichment of the surface with chromium (e.g., by 'chromising' diffusion treatment) offers a logical method of improving oxidation-resistance. In this paper the authors report the results of experiments carried out to determine the effects of such treatment on the oxidation characteristics of alloys and steels representative of commercially available materials.

Chromised specimens of the following materials were oxidised in air, at temperatures in the range 700°-1000°C., and their oxidation-resistance was assessed on the basis of weight-gain determined at 24-hour intervals: dead-mild steels and medium- and high-carbon steels; low-alloy chromium-molybdenum-vanadium and chromium-nickel-molybdenum steels; a complex nickel-chromium-cobalt creep-resisting austenitic steel; three nickel-chromium-cobalt-iron-base heat-resisting alloys; and two cobalt-chromium-iron-nickel-base heat-resisting alloys. After testing, each specimen was subjected to metallographic examination to reveal the nature of the oxidation and to determine the effects upon the microstructure.

The conclusions drawn from the experimental results (which in the paper are preceded by a short review of the general characteristics of chromium diffusion) are summarised by the authors as follows:

'It seems clear that surface chromium diffusion can provide better oxidation-resistance for a wide range of materials. Such treatment does not necessarily alter the bulk properties of an alloy, which may well have been formulated with properties other than oxidation-resistance primarily in mind. Plain-carbon and low-alloy steels, materials that are not inherently oxidation-resistant, can be very considerably protected by a surface layer of chromium-rich alloy, and thereby brought to the level of a high-alloy steel. When intrinsically oxidation-resistant materials, such as high-alloy steels and nickel- or cobalt-base materials, are chromised, the treatment often has the useful dual effect of further lowering the rate of oxidation and of altering the nature of the oxidation, which may, in the untreated material, proceed in an undesirable manner, such as by intergranular penetration.

'We have represented each group of materials by typical examples; this paper does not by any means cover the whole range of available alloys and treatments. Particularly when dealing with complex alloys, it is difficult and indeed dangerous to generalise, and each case must be studied separately. However, the results described above apply broadly (though

not quantitatively) to many other alloys in the respective groups.

'Chromium-diffusion can also produce a marked reduction in the oxidation rates of many alloys in the presence of the combustion products of fuels, such as CO, CO_2, SO_2, H_2S, etc. This is a wide subject that cannot be considered within the scope of simple thermal oxidation.'

Oxidation of Iron-Nickel Alloys

R. T. FOLEY and C. J. GUARE: 'The Oxidation of Iron-Nickel Alloys. III. Kinetics of Oxidation of Three Commercial Alloys.'

Jnl. Electrochemical Soc., 1959, vol. 106, Nov., pp. 936–40.

Three commercial iron-nickel alloys (two containing 30 and 41 per cent. of nickel, respectively, and the third 78 per cent of nickel and 4 per cent. of molybdenum) were oxidised at 600°, 700°, 800°, 900° and 1000°C. in two atmospheres: air, and a mixture of oxygen and nitrogen (nitrogen 78·3, oxygen 21·7, per cent.). Change in weight was determined by means of a Chevenard thermobalance, and the oxidation products were studied by electron-diffraction techniques, using equipment which permitted the study to be made at the temperature of reaction. (The equipment is described in Part II of the series, 'Electron Diffraction at High Temperatures': see abstract in *Nickel Bulletin*, 1957, vol. 30, No. 9, p. 164.)

The oxidation of the alloys followed a parabolic weight-gain/time relationship during the 60-minute reaction period. Replicate experiments showed that, in general, the parabolic-rate constants determined for the oxygen/nitrogen mixture exhibited less variation than those determined for an air environment, an effect which was probably the result of day-to-day changes in the composition of the laboratory air. The influence of temperature on the reaction rates was determined by means of an Arrhenius-type equation. Both the reaction rates and apparent energies of activation of the 30 and 41 per cent. nickel alloys were consistent with a rate-determining process of cation diffusion through a spinel structure $Ni_xFe_{3-x}O_4$. The hypothesis is made that the apparent energy of activation for the 78 per cent. nickel alloy is due to the influence of the 3·8 per cent. molybdenum content on the physical characteristics of the film.

The anomalously high rates observed in both atmospheres at the higher temperatures studied are discussed in relation to 'over-temperatures' resulting from heat generated at the surface by oxidation.

Internal Oxidation of Nickel-base Alloys

W. M. SCHWARZKOPF: 'Internal Oxidation of Nickel-base Alloys.'

Zeitsch. f. Elektrochemie, 1959, vol. 63, Oct., pp. 830–2; disc., pp. 832–4.

In a paper discussing dispersion-hardening methods of strengthening materials for high-temperature service SCHWARZKOPF and GRANT alluded, *inter alia*, to the use of internal oxidation as a means of producing an appropriate dispersion of fine oxide particles in the alloy (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 11, pp. 332–3), a method, however, which is effective only if the alloying phase to be oxidised exhibits a greater affinity for oxygen than the basis metal. The work on dispersion-hardening by oxidation reported in the present paper was carried out on binary nickel alloys containing 0·5–10 wt. per cent. of chromium or 0·5–4 wt. per cent. of aluminium.

Small cubic specimens of the two series of alloys, produced from heats melted under an argon atmosphere, were heated (under an argon atmosphere for the first hour, and at temperatures in the range 700°–1300°C.) in contact with a mixture of NiO and nickel powder. The pressure used was that of dissociation of the nickel oxide, which therefore comprised the source of oxygen. After oxidation the specimens were subjected to metallographic examination. In other experiments the nickel alloys were oxidised in powder form, and the oxidised powders were then used to obtain specimens for determination of high-temperature properties.

It was found that internal oxidation was possible only when the alloys contained less than 4 wt. (8·3 at.) per cent. of aluminium or 9 wt. (10 at.) per cent. of chromium. At higher concentrations, diffusion of the atoms of the alloying addition to the surface of the alloy, or to the sub-scale already formed, was sufficiently rapid to inhibit penetration of oxygen into the alloy; alternatively, the number of atoms present at the surface in the initial stages of oxidation was sufficiently high to ensure the formation of a thick oxide film which inhibited further reaction.

In alloys of a composition permitting internal oxidation, the rate of penetration during oxidation obeyed a parabolic law. The size of the oxide particles increased, with rise in the temperature of oxidation, from less than 0·1μ at 700°C. to 10μ at 1300°C. The mechanical properties of the alloys, being governed by the size and distribution of the oxide particles, were related to the temperature of internal oxidation: creep data illustrating this relationship are presented.

Relationship Between the Microstructure and Mechanical Properties of Titanium-Carbide/Nickel Cermets

I. BINDER and R. STEINITZ: 'An Investigation of the Mechanical Properties of Cermets as Related to the Microstructure.'

Wright Air Development Center, Tech. Report 58–432, Jan. 1959; 86 pp.

Whilst the classical concept of a cermet has been that the hard phase forms a rigid skeleton and the metallic binder fills the interstices (the skeleton material determining the strength of the cermet and the binder providing the necessary toughness or impact-resistance), it has been shown in recent years by GURLAND and NORTON that in many tungsten-carbide/cobalt cermets a rigid skeleton is not present

(see *Trans. Amer. Inst. Mechanical Engineers*, 1952, vol. 194, p. 1051). According to GURLAND and NORTON, the high strength and brittleness of a cermet can be attributed to 'the mechanical restraint exerted by the carbide particles upon the films of the binder, and to the complex state of stress resulting from the presence of residual stresses of thermal origin'. Such a stress system would depend to a large degree upon the microstructure, and, on the basis of this hypothesis, brittleness becomes a structure-sensitive property. The possibility is presented therefore of altering the brittle nature of a cermet by modifying the microstructure. The investigation now reported was initiated to determine whether variations in the properties of cermets could be correlated with changes in their microstructure.

The report is introduced by a summary of the findings of a survey of the literature. On the basis of this survey, titanium carbide was selected for use as the hard phase and nickel as the binder, and, to minimise the variables involved, the tests were conducted using a 60–40 titanium-carbide/nickel composition.

In preliminary tests, in which various pressing and sintering conditions were investigated, it was found that the samples exhibiting the highest reproducibility were obtained by cold-pressing and subsequent sintering *in vacuo*, preferably for fairly short times (30–60 minutes) at intermediate temperatures (1200°–1400°C.), and these ranges were therefore accepted as standards in the production of the large number of samples required in the main test programme. A study was made of the influence of the following factors: (1) Variation in the original particle size of the titanium carbide; (2) Addition of a small amount of molybdenum to the binder to influence wettability; (3) Addition of a small amount of copper to the titanium carbide to influence wettability or particle shape; (4) Milling in a tungsten-carbide mill as opposed to a steel mill; (5) Adding the nickel to the titanium carbide before and after ball milling the titanium carbide. Specimens from the cermets so produced were then subjected to tests to determine their density, electrical resistivity, impact-strength, and transverse rupture-strength at room temperature and 1000°C. (In stress-rupture tests the life of the first specimens tested was so small that further evaluation in this connection was discontinued.) In the final phase of the programme specimens representative of those subjected to the room-temperature transverse rupture tests (and, in some cases, of those tested at 1000°C. and in the impact tests) were metallographically examined, and an attempt was made to correlate the microstructural findings with the mechanical properties previously determined. Details are given of the materials and test procedures used in the investigation, and the data obtained are fully presented. In discussing the results the authors make reference to numerous photomicrographs.

Correlation of microstructures with mechanical properties was difficult due to the similarity of the microstructures. Moreover, it is noted that the greatest changes in strength may well be more dependent upon the addition or pick-up of a small amount of a specific 'impurity' rather than to major changes in microstructure. (These small impurities, such as the copper addition or the tungsten-carbide picked up during ball milling, did not show up separately in the microstructures.) The factor which appeared to have a major influence on physical properties was the average grain-size. In general, a fine grain-size was associated with high strength, especially if the fine-grained structure did not contain many grains of a size much larger than average. Moreover, a generally fine-grained structure with the grains agglomerated in large clusters (with porosity between) was not associated with high strength. An estimate of the average particle size of the specimens revealed a distinct correlation between this factor and physical properties. High strength appeared to be associated also with uniform distribution of the binder phase, but such effects are considered to be less important than the effect of grain-size.

Influence of Vacuum-Induction, Vacuum-Arc and Air-Induction Melting on the Properties of a Nickel-base Heat-Resisting Alloy

R. F. DECKER, J. P. ROWE and J. W. FREEMAN: 'Vacuum-Induction, Vacuum-Arc and Air-Induction Melting of a Complex Heat-Resistant Alloy.'

Nat. Aeronautics and Space Administration, Tech. Note D-6, Aug. 1959; 43 pp.

The object of the work reported was to establish the influence of melting variables on the properties of high-temperature alloys, and thereby to throw light on the mechanism underlying the variations in properties associated with different heats of such materials. In an earlier investigation, restricted to vacuum-induction melting, a major cause of these variations was shown to be the boron and/or zirconium contents of the heats (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 12, p. 370). The work now described widened the scope of the programme to take into account not only the effects of vacuum-induction melting but also those of air-induction melting and of vacuum-arc melting in a cold mould.

The following composition was aimed at in the heat-resisting alloy selected for study: chromium 20, cobalt 15, molybdenum 4, titanium 3·1, aluminium 3·1, silicon 0·12, manganese 0·12, carbon 0·08–0·15, per cent., remainder nickel. Boron and zirconium contents were varied to permit comparison of the effects of the melting method on materials containing comparable amounts of these influential elements. The rôle played by oxygen, nitrogen and phosphorus was studied by means of a melting technique developed to permit their addition to certain boron-containing heats of the alloy after vacuum melting. The hot-workability of the various heats was assessed by qualitative comparison of surface cracking after rolling, and creep-rupture properties were determined, at 1600°F. (870°C.), on specimens in the aged condition. Variations in properties were related to the effects of melting practice on the composition of the

heats, and an attempt was made to interrelate microstructure, properties and composition.

The data recorded show that the level of the boron and/or zirconium contents had a considerably greater influence on properties than the melting method. Vacuum melting did, however, reduce corner cracking, gave an improved surface during hot rolling, and resulted in more uniform properties within heats. Slightly higher creep-rupture properties were determined in vacuum heats with low boron + zirconium contents or in zirconium-containing heats, but little advantage was conferred by high boron contents, and with high boron + zirconium additions the properties of air-melted heats were superior. Vacuum-melted heats contained fewer oxide and carbonitride inclusions, but this difference appeared to be a function of the opportunity available to the inclusion to separate from heats containing high oxygen and nitrogen contents. The removal of phosphorus by vacuum melting could not be correlated with the properties of the heat.

A study of the rôle of oxygen and nitrogen indicated that the two elements had a beneficial effect on ductility in creep-rupture tests, and the data suggest that vacuum melting removes unidentified elements detrimental to ductility. Oxides and carbonitrides did not *per se* initiate microcracks. Carbonitrides present in the grain boundaries of air-melted heats did, however, initiate microcracks, but their relationship, and that of the oxygen and nitrogen contents, to microcracking was not clear. The presence of oxygen and nitrogen increased corner cracking during hot-rolling, but was not responsible for the poor surface which resulted from rolling air-melted heats.

Physical and Mechanical Properties of Precipitation-Hardenable Stainless Steels

D. A. ROBERTS, D. B. ROACH and A. M. HALL: 'Physical and Mechanical Properties of Nine Commercial Precipitation-Hardenable Stainless Steels.'

Defense Metals Information Center, Battelle Memorial Inst., Report 112, May 1, 1959; 13 pp. + appendices.

The ease with which the precipitation-hardenable grades of chromium-nickel stainless steel can be hot-worked, machined, formed and joined, and the high strength obtainable by refrigeration and ageing treatments, their satisfactory performance at temperatures as high as 1300°F. (705°C.), and their excellent corrosion- and oxidation-resistance render them particularly attractive for aeronautical and similar applications. Three types of precipitation-hardenable steel are commercially produced (i.e., martensitic, semi-austenitic and austenitic), all of which are available in a variety of forms. This report presents data on the physical and mechanical properties of nine commercially important precipitation-hardenable stainless steels.

The data, obtained from literature published by the makers, relates to the following steels:

Martensitic: 'Stainless W', '17-4 P.H.'

Semi - Austenitic: '17 - 7 P.H.', 'P.H. 15 - 7 Mo', 'AM-350', 'AM-355'.

Austenitic: 'A-286', '17-10P', 'HNM'.

Recommended heat-treatments and typical physical properties are listed, and, where the information is available, data on mechanical properties are given, in the following order, in appendices to the report: room-temperature and elevated-temperature tensile, compressive and hardness characteristics; torsion properties ; shear properties ; impact-resistance ; fatigue-strength; stress-rupture properties; creep properties; tensile and compressive stress-strain curves; isochronous stress-strain curves for the steels at elevated temperatures. No attempt is made to evaluate the merits of individual steels, and data on weldability and corrosion-resistance are excluded from the report.

In summarising the general characteristics of the three types of steel the authors point out that, though in the annealed condition the martensitic grades lack the ductility required for extensive forming operations, they can be hardened to yield strengths of about 180,000 p.s.i. (80·5 t.s.i.; 126·5 kg./mm.^{2}) by a simple ageing treatment in the range 900°-950°F. (480°-510°C.). The semi-austenitic types are ductile and readily fabricated in the annealed condition, but require complex heat-treatments for full hardening. Depending upon the heat-treatment employed, steels of the latter type can, however, be hardened to yield strengths in the range 175,000-225,000 p.s.i. (78-100·5 t.s.i.; 122-158 kg./mm.^{2}). As-annealed, the austenitic grades are ductile and readily formed, and are hardenable, by a simple ageing treatment in the region of 1300°F. (705°C.), to yield strengths in the range 70,000 - 100,000 p.s.i. (31 - 44·5 t.s.i. ; 49 - 70·5 kg./mm.^{2}).

The austenitic grades can be used for applications involving temperatures up to about 1300°F. (705°C.); the maximum service temperatures for which the martensitic and semi-austenitic types are suitable fall within the range 600°-700°F. (315°-370°C.).

Properties and Applications of '17-4 P.H.' Steel

M. E. HOLMBERG: 'Selection and Use of Precipitation-Hardening Stainless Steels.'

Amer. Soc. Mechanical Engineers, 1959, *Paper No.* 59-*PET*-17; 8 pp.

After briefly reviewing the development and characteristics of the three standard grades of stainless steel (ferritic, martensitic and austenitic), the author refers to the evolution, from the chromium-nickel steels, of the precipitation-hardenable grades and, in particular, of the nickel-chromium-copper '17-4 P.H.' steel which, appearing to offer the best combination of properties for applications in the petroleum and petrochemical industries, is selected as the subject of the present paper.

The steel is discussed under two heads: properties and applications. The section on properties includes an explanation of the heat-treatments used and the

designations employed to indicate a specific condition of heat-treatment. Typical mechanical properties associated with various heat-treatments are tabulated. Consideration of the galling characteristics of the steel is followed by a discussion of data illustrating its resistance to stress-corrosion and to corrosion by sea-water. Reference is made also to experiments disproving suggestions that in acetylene operations copper-bearing stainless steels would promote formation of copper acetylide. The steel may be machined in the annealed or hardened conditions, and welding can be carried out without the need for pre-heating.

In reviewing the applications which '17-7 P.H.' steel has already found, the author refers to its use for pump shafts, refinery and sea-water service, safety-relief valves, bolting, and subsurface oil-well equipment.

Mechanical Properties of 'AM-350' and 'AM-355' Stainless Steels

A. W. BRISBANE: 'Mechanical Properties of 'AM-350' and 'AM-355' Stainless Steels.'

Wright Air Development Center, Tech. Report 58-672, Feb. 1959; 45 pp.

The report presents the results of a test programme designed to determine the influence of various heat-treatments on the mechanical properties of the chromium-nickel-molybdenum precipitation-hardenable stainless steels 'AM-350' and 'AM-355'.

The properties of the 'AM-350' grade were evaluated on 0·051-in. (1·275-mm.) and 0·061-in. (1·525-mm.) sheet obtained from two heats of steel. The specimens of the 'AM-355' steel were obtained from $\frac{3}{4}$-in. (1·9-cm.) bar stock. In the case of the sheet material the influence of the following heat-treatments was evaluated:

(1) Refrigeration treatment at −100°F. (−73°C.) for 2 hours.

(2) Refrigeration treatment at −100°F. for 2 hours followed by 2 hours at 750°F. (400°C.).

(3) Refrigeration treatment at −100°F. for 2 hours, followed by 2 hours at 850°F. (455°C.).

(4) Refrigeration treatment at −100°F. for 2 hours, followed by 2 hours at 950°F. (510°C.).

(5) Ageing at 1350°C. (735°C.) for 1 hour, followed by 1 hour at 850°F. (455°C.)

The bar stock was given the same heat-treatment as the sheet material, with the exception that it was annealed at 1750°F. (955°C.) for 1 hour and water-quenched before sub-zero treatment and ageing.

The 'AM-350' specimens were subjected to tensile, compressive and bearing tests at room temperature, and to short-time tensile tests at 400°, 600°, 800° and 1000°F. (205°, 315°, 425° and 540°C.). The room-temperature tensile properties of the 'AM-355' steel were determined on smooth and notched specimens, and Charpy V-notch tests were conducted at room temperature and −90°, 0°, +150° and +300°F. (−70°, −18°, +65° and +150°C.). The data obtained are presented in tabular and graphical form.

The tensile strength of the 'AM-350' steel was found, in general, to be higher than that of such materials as Type 301 18-8 austenitic steel and the precipitation-hardenable steels '17-7 P.H.' and 'Stainless W'. Variation in the ageing treatment had some effect on mechanical properties, heat-treatment (4) resulting in the higher ductility (assessed on the basis of elongation and reduction-in-area), and heat-treatment (1) achieving maximum strength. Little loss in ultimate tensile strength occurred up to 800°F. (425°C.); at higher temperatures the sharp decrease in the values obtained was to be expected since the ageing temperature is 850°F. (455°C.).

Little difference was observed between the longitudinal and transverse properties of the specimens.

Properties of 'Wilco-Wiggin Thermometals'

HENRY WIGGIN AND CO., LTD.: ' 'Wilco-Wiggin Thermometals': Basic Information.'

Publn. 1920*, 1959; 16 pp.

The data contained in the publication relate to the following grades of 'Wilco-Wiggin Thermometals': 'Standard', 'Highflex', 'Rayflex', 'Highflex 45', 'Morflex', 'Midflex 46', 'Highheat', 'Highheat 47', 'Veriflex', 'Autoflex', 'Saflex', 'H.T. Constant', 'Aquaflex', 'Coflex', 'Duraflex', 'Sloflex', 'Muflex', 'Magnaflex', 'Poliflex', 'Cirflex', and the 'R-metals'.

A brief description of the salient characteristics of each of the grades is followed by tables summarising thermal properties and listing constants which, used in conjunction with formulae also presented, permit, for various shapes of 'Thermometal', calculation of temperature deflection and mechanical stiffness, and expression of length and thickness in terms of properties. In subsequent sections notes are given on the fabrication, heat-treatment and mounting of the 'Thermometals'.

Fatigue Characteristics of 'Inconel' at High Temperatures

R. G. CARLSON: 'Fatigue Studies of 'Inconel'.'

Battelle Memorial Inst., Report BMI-1355, June 26, 1959; 20 pp.

Components of reactors are often subjected to mechanically- or thermally-induced cyclic stress. The present report summarises one phase of a comprehensive study of the nature of deformation and fracture in materials stressed at elevated temperatures which is being conducted with the aim of obtaining data relevant to the design of reactor components.

The phase described was concerned with determination of the relationships between temperature, stress, strain, fatigue life, and cyclic frequency during tests on 'Inconel' specimens under fully alternating stress-cycling conditions at elevated temperatures. The pertinent fatigue data were derived from tests performed under three conditions: (1) 1500°F. (815°C.)

* *We shall be pleased to supply a free copy of this publication.*

at 60 cycles/minute, (2) 1300°F. (705°C.) at 60 cycles/minute, (3) 1500°F. (815°C.) at 6 cycles/minute. In each case the specimens were subjected to stresses of a magnitude which would produce failure within 10^3 to 10^5 cycles. During each test cyclic-load/time and cyclic-strain/time traces were obtained, from which stress/strain hysteresis curves were plotted. The traces and hysteresis curves then permitted determination of the pertinent relationships between stress, strain and cycles.

The limited number of tests and testing conditions studied made it difficult to draw any general conclusions concerning the behaviour of 'Inconel' during stress cycling. The following observations are, however, made:

'1. Fatigue-strength, whether measured in terms of stress, total strain, or plastic strain, was found to be a function of both temperature and frequency.

'2. The relationship between plastic strain and life-time, represented by $N^{\alpha}\Delta\varepsilon\rho = K$, may be approximately valid for 'Inconel' under the conditions studied, although other relations fit the observed data as well, or better.

'3. The relationship between stress and strain, within the range of test conditions and lifetimes studied, varies with cycles of stress reversal, never reaching an equilibrium condition.

'4. The strain behaviour of a specimen during stress cycling is not continuous. Strain in the plastic region sometimes occurs in sudden step-like increments, which are predictable functions of temperature, stress, frequency and cycles.'

Fatigue Characteristics of 'INOR-8' at High Temperatures

R. G. CARLSON: 'Fatigue Studies of 'INOR-8'.'

Battelle Memorial Inst., Report BMI-1354, June 26, 1959; 16 pp.

The test programme reported was carried out to obtain design data relevant to the use of the nickel-molybdenum-chromium heat-resisting alloy 'INOR-8' for reactor components. It is known that temperature generally influences the fatigue-strength of a material, but little information is available on the effects of the stress-cycle frequency. The particular aim of the investigation was, therefore, to determine whether the fatigue-strength of 'INOR-8' would vary with the frequency of the applied stress cycle at high temperatures.

Reversed-bending fatigue tests were conducted on annealed specimens of 'INOR-8' at 1100°, 1300° and 1500°F. (595°, 705° and 815°C.), using cyclic frequencies of 100, 600 and 3000 cycles/minute. The data obtained are plotted in the report in the form of stress/life-time curves.

Fatigue-strength was found to decrease with increase in temperature, but the frequency of the applied-stress cycle was found to have no appreciable effect at temperatures up to 1300°F (705°C.). At 1500°F. (815°C.), however, the fatigue-strengths of specimens tested at frequencies of 600 and 3000 cycles/minute were equal, while at a frequency of 100 cycles/minute fatigue-strength was substantially lower. The studies indicated the existence of a critical frequency, associated with each of the test temperatures, above which fatigue-strength is unaffected by, and below which fatigue-strength decreases with decrease in, the frequency of the stress cycle.

Tests on two specimens of different grain-size showed that that with the finer grain exhibited the higher fatigue-strength.

Sliding Characteristics of Nickel and Nickel Alloys at High Temperatures

M. B. PETERSON, J. J. FLOREK and R. E. LEE: 'Sliding Characteristics of Metals at High Temperatures.'

Amer. Soc. Lubrication Engineers, 1959, *Preprint* 59*LC*-5; 14 pp. + figures and tables.

Previous studies of the friction, wear and surface damage associated with contact bearings sliding against each other at elevated temperatures had indicated that surface films (mainly oxides) play an important rôle in preventing seizure and galling. To gain a better understanding of the frictional characteristics of metals during high-temperature sliding, and to throw light on the rôle of surface oxides in this respect, tests were carried out on various metals sliding against themselves.

Iron, copper, cobalt, nickel, molybdenum, chromium, aluminium and zirconium were selected for study, using a hemispherical specimen sliding against a flat plate. The specimens were first tested for half an hour at the desired temperature, and then the temperature was either increased or decreased as sliding continued. The coefficient-of-friction/temperature-cycle curves so obtained are presented in the paper.

With increase in temperature, a considerable increase in friction and surface damage occurred as the material softened, and this increase persisted until a temperature was reached at which an oxide film was continually re-formed at the sliding surface. At this temperature the sliding characteristics were markedly improved. With metals such as cobalt and zirconium sufficient oxide was formed at room temperature to be beneficial, but, with the other materials, higher temperatures were required to permit formation of sufficient oxide. (Any temperature effect which tends to remove the oxide film, such as softening, scaling or sublimation, causes a rise in friction.) The transition-temperature range for iron, copper, nickel, molybdenum and chromium was, respectively: 100°-200°F. (40°-95°C.); 400°-500°F. (205°-260°C.); 1200°-1400°F. (650°-760°C.); 800°-900°F. (425°-480°C.); and 800°-1100°F. (425°-595°C.).

The friction data obtained for the metals studied are compared in the paper with similar data derived from tests on materials in which the metals are present as alloying additions: i.e., an aluminium alloy, two nickel-chromium-iron-base alloys, a nickel-molybdenum-chromium-base alloy, a nickel-copper-base alloy, tool steel and carbon steel. A relationship was established between the friction properties of the

alloys and those of their major constituents, a reduction in friction occurring at a temperature sufficient to promote oxidation of the constituent with the lowest oxidation-resistance.

Sliding tests were also run on the two nickel-chromium-iron-base alloys using powdered oxides as lubricants. At 1300°F. (705°C.) a number of the oxides (WO_3, Cu_2O, ZnO, Co_2O_3 and PbO) proved effective as solid lubricants, and, since the softer of the oxides studied were the more effective, it is suggested that metals which form such oxides would exhibit the most satisfactory sliding characteristics at high temperatures.

Materials for High-Temperature Gear Applications

E. G. JACKSON, C. F. MUENCH and E. H. SCOTT: 'Evaluation of Gear Materials Scoring at 700°F.'

Amer. Soc. Lubrication Engineers, 1959, *Preprint* 59*LC*-6; 26 pp.

The information presented in the paper is closely cognate with that recorded, by E. H. ROWE and the present authors, in *Wright Air Development Center Tech. Report* 58-546: see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 9-10, pp. 288-9.

Development of Nickel-containing Seal Materials: High-Temperature Wear Tests

R. H. BASKEY: 'An Investigation of Seal Materials for High-Temperature Application.'

Amer. Soc. Lubrication Engineers, 1959, *Preprint* 59*LC*-8; 30 pp.

In connection with research to develop materials suitable for use in rotating seals intended for aeronautical applications involving high speeds and temperatures and no lubrication, a systematic study was made of the wear characteristics of three groups of material: (1) the refractory 'hard metals' MoB, CrB_2, WSi_2, CrN, VSi_2, WB, VB_2, $CrSi_2$, Ti_5Si_3, VN, and TiB_2; (2) binary compositions formed by bonding the first six of the materials in group (1) with various amounts of nickel; (3) ternary compositions formed by infiltrating the binary alloys with various amounts of silver. The results of the investigation are recorded in the present paper.

The binary and ternary compositions were produced by powder metallurgy, and the nickel or nickel + silver additions were intended to induce the formation of a solid lubricating film which would, in service, compensate for the lack of liquid lubrication. Specimens of each material studied were held, at temperatures in the range 75°-1250°F. (25°-675°C.), against discs of tool steel or nickel-chromium-iron alloy rotating at speeds up to 29,000 ft./min. (8700 m./min.). These tests were supplemented by others in which specimens of a commercially available titanium-carbide cermet containing (nickel 25, molybdenum 5, niobium 4·5, tantalum 0·03, per cent.) were held against a disc of the same material.

Full details are given of the experimental apparatus and procedures employed and the data obtained. The author's evaluation of the results leads him to draw the following conclusions:

'1. One pure refractory hard metal, i.e., MoB, indicated satisfactory wear patterns and rates against tool steel. None of the pure refractory materials was suitable against a disc composed of a nickel-chromium-iron alloy.

'2. Binary alloys composed of nickel and refractory hard metals were not satisfactory against either tool steel or a nickel-chromium-iron alloy.

'3. The addition of silver, to form ternary alloy systems with nickel-bonded refractory metals, was distinctly beneficial in achieving superior wear-resistance at elevated temperatures. The ternary alloys containing high percentages of WB (60-90 wt. per cent.) showed superior wear qualities against tool steel. Ternary alloys composed mainly of CrN displayed similar qualities against both tool steel and a nickel-chromium-iron alloy.

'4. A commercial titanium-carbide composition rubbing against a similar material had excellent wear properties at elevated temperatures. However, this material was tested at about half the sliding velocity used in the other material investigations.'

Heat-Resisting Coatings for Use on 'Thermold J' Tool Steel

E. B. NORRIS: 'High-Temperature Coatings for Chromium Hot-Work Tool Steels.'

Wright Air Development Center, Tech. Report 58-269, Oct. 1958; 84 pp.

Coatings capable of conferring the necessary oxidation- and corrosion-resistance on hot-work die steels can render them suitable for applications involving temperatures as high as 1000°F. (540°C.). The work reported was carried out to evaluate various commercially available coating processes for this purpose.

'Thermold J'* was selected for investigation as a typical hot-work die steel, and the suitability of the following types of coating was assessed: (1) nickel-phosphorus alloy, (2) nickel-zinc alloy, (3) nickel-cadmium alloy, (4) nickel-tin alloy, (5) 'Alumicoat' aluminium coating, (6) nickel, (7) 'Solaramic', 'Alcermet' and 'Aluminised' coatings, (8) aluminium-silicone paint. Coatings (1) to (4) were deposited by plating (coating (1) by electroless plating, the others by electrodeposition) and then diffused by heat-treatment. Coating (5) was produced by hot-dipping (followed, in the case of some specimens, by diffusion-treatment), while coatings (7) were sprayed on to the basis metal and then fired. The nickel coatings were electrodeposited from a Watts bath or from a sulphamate solution.

In the initial screening programme, coated specimens of 'Thermold J' sheet were subjected to: oxidation

* Carbon 0·52, silicon 1·09, manganese 0·35, sulphur 0·007, phosphorus 0·027, chromium 5·08, nickel 1·53, molybdenum 1·4, vanadium 0·99, per cent.

tests at 1000°F. (540°C.); bend tests; salt-spray tests after exposure for various times to high temperatures (500°, 750° and 1000°F.: 260°, 400° and 540°C.); atmospheric-corrosion tests, in the as-coated condition and after being soaked at 500°, 750° and 1000°F. On the basis of these preliminary tests, the following six coatings were selected for further evaluation: the nickel-phosphorus alloy, the nickel-zinc alloy, the 'Aluminised' coatings, undiffused 'Alumicoat', aluminium-silicone paint, and nickel electrodeposited from a Watts solution. This further evaluation comprised abrasion tests; thermal-shock tests (cycling between 1000° and 300°F. (540° and 150°C.)); tensile tests at room-temperature and 500° and 1000°F.; stress-rupture tests on notched and smooth specimens; and fatigue tests. In most cases these tests were carried out also on specimens previously exposed to high temperatures.

Of the six coatings, the nickel-zinc alloy offered the most promising combination of properties. Its resistance to abrasion and thermal-shock was good, while the coating process had no adverse effect on the tensile and stress-rupture properties of the basis metal. Fatigue-strength was, however, reduced.

The performance of the nickel-phosphorus coating compared favourably with that of the nickel-zinc alloy, but its resistance to thermal shock was relatively low. Nickel deposited from the Watts solution, although reducing the endurance limit of the basis metal to a greater degree than any other coating tested, exhibited excellent resistance to abrasion and thermal shock and had no deleterious effect on tensile and stress-rupture properties.

Fatigue-strength, tensile-strength, and stress-rupture properties of the basis metal were unaffected by the application of aluminium-silicone paint, but the coating offered little resistance to abrasion and thermal shock. The 'Alumicoat' and 'Aluminising' processes, which involved exposure to temperatures higher than 1200°F. (650°C.), had a tempering effect on the basis steel which reduce strength, hardness and stress-rupture life. Fatigue-strength was also adversely affected, and abrasion-resistance was only moderate.

Fuel-Oil-Ash Corrosion of Nickel-containing Heat-Resisting Alloys

CORROSION I COMMITTEE, COUNCIL OF BRITISH MANUFACTURERS OF PETROLEUM EQUIPMENT: 'Corrosion of Heat-Resisting Alloys in the Presence of Fuel-Oil Ash.'

Brit. Petroleum Equipment News, 1959, vol. 7, Autumn, pp. 54–69.

In 1950, following consideration of the information then available, the Council of British Manufacturers of Petroleum Equipment decided to initiate research on fuel-oil-ash corrosion of selected heat-resisting alloys under actual combustion conditions. The primary aim of the study was to apply the data obtained to extending the life of tube supports and hangers in oil-distillation plant employing crude-oil residues for firing. The C.B.M.P.E. Technical Committee organising the tests therefore decided that the specimens should be in the form either of rectangular section bars or of brackets similar in shape to the tube supports in a distillation plant, but subsequently the scope of the investigation was widened, and test specimens prepared from the original bars and brackets were finally exposed in oil-fired boilers at the Bankside Generating Station, London, at the Haifa Power Station, and in S.S. Nestor.

This report, which summarises the scope and results of the investigation, was compiled from data on test conditions recorded during the operation of the boilers, and from the data derived from examination of the corroded specimens in the laboratories of several companies represented on the Committee*.

The composition of the heat-resisting materials selected for study is reproduced in the table, p. 24. The nickel content was the main variable studied, but most of the alloys were typical of commercially available compositions, the characteristic features of which gave rise to superimposed variables (such as differences in chromium, silicon, manganese or carbon contents) or to the presence in some of the alloys of small amounts of niobium, titanium or tungsten. The silicon content of two alloys of the same basis composition was varied intentionally. Full details are given of test locations.

After exposure, the appearance and weight of the specimens was recorded, and samples of scale and deposit were scraped off for examination by emission spectrography and X-ray diffraction. Small samples cut from the specimens were supplied to various Committee members for micro-examination, and, in some cases, semi-quantitative analysis by emission spectrography was checked by chemical analysis.

The results of the investigation are presented *in extenso*, and the data are supplemented by photo-macro- and photomicrographs of the corroded specimens. In assessing the data, the nature and extent of the corrosion are related to the nickel content of the alloys and to the relative proportions in the deposits of sodium and vanadium (present, respectively, as sodium sulphate and as vanadium pentoxide or vanadates). Within the limits of the conditions studied, and on the basis of this correlation, the following conclusions are considered justified:

'1. The combustion of fuel oil in the boilers of steam-raising plant gives rise to ash deposits which, by virtue of the presence of vanadium pentoxide and sodium sulphate, may be corrosive to nickel-chromium or nickel-chromium-iron alloys containing 17·1 to 24·3 per cent. chromium and 10 to 77·8 per cent. nickel. The relative proportions of sodium and vanadium in the deposits determines which of these alloys are most susceptible to attack.

'2. Deposits of high vanadium content accelerate oxidation primarily by exerting a fluxing action on the oxide scale: they are most corrosive to austenitic alloys of low nickel content. Deposits of high

*The results of laboratory corrosion tests on the same alloys, and a comparison of these with the results of the field tests, will form the subject of a later paper.

Composition and Condition of Alloys Studied in Oil-Ash-Corrosion Tests

(*See abstract on p. 23*)

Condition	Composition						
	C %	Si %	Mn %	Ni %	Cr %	Fe %	Other Elements %
Cast ..	0·35	0·4	1·0	0·2	25·8	bal.	N 0·033
Cast ..	0·14	0·7	0·9	10·9	18·3	bal.	Nb 1·2
Cast ..	0·18	1·5	0·9	22·1	24·3	bal.	—
Wrought ..	0·06	0·7	0·5	31·8	18·4	bal.	Ti 1·2
Cast ..	0·71	1·7	—	37·0	19·8	bal.	W 1·4
Cast ..	0·64	1·0	—	53·9	17·1	bal.	W 0·7
Cast ..	0·20	2·2	0·8	59·7	20·1	bal.	—
Cast ..	—	5·6	—	bal.	19·9	10·2	—
Cast ..	—	1·3	—	bal.	20·0	10·0	—
Wrought ..	0·13	0·4	0·2	bal.	19·3	2·0	Ti 0·2

sodium-sulphate content accelerate oxidation through the agency of sulphur contamination: such deposits are most corrosive to alloys of high nickel content. Both mechanisms contribute to corrosion by deposits of intermediate composition, which is most severe in alloys of intermediate nickel content.

'3. Nickel-chromium-iron alloys of intermediate nickel content (30 to 60 per cent. nickel) are susceptible to severe attack by deposits containing vanadium and sodium in all proportions, though this susceptibility appeared to be reduced in two alloys (37·0 and 53·9 per cent. nickel) with high carbon contents and tungsten present. A measure of resistance to corrosion by high-vanadium deposits (vanadium more than about two-thirds of the sodium content) is shown by alloys containing more than 60 per cent. nickel: similarly, alloys containing up to 20 per cent. nickel are relatively resistant to attack by deposits of low vanadium and high sodium-sulphate contents (vanadium less than two-thirds of the sodium content).

'4. Deposits of ash in the superheater zones of land-based boilers tend to have a higher V/Na ratio than that of the original oil, due presumably to preferential deposition of vanadium: the deposit ratio of two-thirds as much vanadium as sodium was achieved when the oil contained approximately one part vanadium to four parts sodium.

In installations operating at sea, ash deposits are likely to be enriched by sodium contamination and, in spite of preferential vanadium deposition, the V/Na ratio may be less than in the oil.

'5. Only a ferritic 0·35 per cent. carbon-25·8 per cent. chromium steel showed good resistance to attack by deposits containing sodium and vanadium in all proportions. This type of alloy has relatively poor stress-carrying capacity at high temperatures and may, therefore, be unsuitable for heavily stressed components.'

Failure of Nickel-containing Heat-Resisting Alloys and Steels Used in Gas-Carburising Furnaces

G. POMEY: 'Structural Changes in Heat-Resisting Steels and Alloys Used in Gas-Carburising Furnaces.' *Mémoires Scientifiques de la Revue de Métallurgie*, 1959, vol. 56, Oct., pp. 471–82; disc., pp. 482–3.

The paper presents the findings of a comprehensive investigation initiated to throw light on the factors which contributed to the failure of heat-resisting alloys and steels used as materials of construction in gas-carburising furnaces.

The alloy and steel specimens studied were of the following nominal composition (and were, in most cases, austenitic): 20 Ni-25 Cr, 35 Ni-20 Cr, 46 Ni-27 Cr-5 W and 56 Ni-12 Cr. All had formed part of equipment used in industrial furnaces which, for all but 24 hours of the week, were operated at 950°C. or (when case-hardening was effected using nitrogen as well as carbon) 825°C. For 24 hours at the end of the week the furnaces were allowed to cool, in an air atmosphere, to a temperature in the range 150°–400°C., and once a week soot was burnt off the walls of the furnace by compressed air. Some of the pieces examined were subjected during service only to thermal stresses; other (e.g., turbine parts) were subjected also to mechanical stress.

Using microscopical, X-ray-diffraction and micro-analytical techniques, the author was able to determine the nature, crystallographic structure and chemical composition of the phases present, and to establish the mechanism by which the microstructural changes, and therefore failure, occurred. The metallographic and other findings are described in detail, and numerous photomicrographs are included in the paper.

The author concludes that the mechanism leading to failure involves three stages:

During the carburising period, carbide precipitation

($M_{23}C_6$, M_7C_3, Cr_3C_2) causes chromium impoverishment in the matrix. This impoverishment is most severe at the surface in contact with the gas and decreases with distance from the surface.

During the following oxidising period (cooling in air at the end of the week, burning away of soot), superficial and internal oxidation occurs.

Under the action of the stresses to which the component is subjected, fissures originate in the surface and progress along the boundaries of oxidised grains, while the precipitation of carbides and sigma causes the body of the component to become embrittled. Failure then occurs as a result of mechanical or thermal shock.

It is suggested that the service life of such components can be lengthened by suitable modification of the operational conditions and of the composition of the steel. Chromium impoverishment can be combatted by ensuring a sufficiently high chromium content (15–25 per cent.), adjusted, as a function of the nickel and iron contents, to minimise the risk of sigma-phase formation. Carburising temperatures should be higher than that at which the sigma phase is stable. Oxidation and thermal stressing are best avoided by eliminating the weekly shut-down, but suggestions are made as to ways of decreasing such stressing by modification of the service conditions. Oxidation-resistance can be improved by addition of elements with greater carbide-forming tendencies than chromium (e.g., silicon and aluminium), or perhaps by application of protective coatings.

Corrosion- and Heat-Resistant Steel Plate: Specification

SOC. AUTOMOTIVE ENGINEERS: 'Steel Plate, Corrosion- and Moderate Heat-Resistant 15·5Cr–4·5Ni–2·9Mo–0·1N.'

S.A.E./A.M.S. Specification 5549, issued November 1, 1959.

The material covered is primarily for use in applications requiring high-strength and oxidation-resistance at temperatures up to 800°F. (425°C.), and where parts are welded during fabrication.

The following composition range is stipulated: carbon 0·1–0·15, silicon 0·5 max., manganese 0·5–1·25, sulphur 0·03 max., phosphorus 0·04 max., chromium 15–16, nickel 4–5, molybdenum 2·5–3·25, nitrogen 0·07–0·13, per cent.

Property requirements are laid down for plate in the annealed condition, and after austenite conditioning, sub-zero treatment, and tempering.

Properties of Cold-Rolled Austenitic Stainless Steel

R. J. MANGONE, D. B. ROACH and A. M. HALL: 'Properties of Certain Cold-Rolled Austenitic Stainless Sheet Steels.'

Defense Metals Information Center, Battelle Memorial Inst., Report 113, May 15, 1959; 10 pp. + appendices.

The purpose of the report is to provide, under one cover, all the information available on the properties of cold-rolled austenitic stainless steels used, or being considered for use, in aeronautical applications.

The data presented relate to the following steels (in sheet form): A.I.S.I. Type 301 (18–8 chromium-nickel steel); 'MicroMach' (17–7-type chromium-nickel steel); A.I.S.I. Type 201 (chromium-manganese-nickel steel); 'USS Tenelon' (chromium steel); 'USS 17–5 MnV' (chromium-manganese-nickel-vanadium steel). Notes on the composition and salient characteristics of each steel are followed, in appendices to the report, by tabular and graphical data summarising physical properties and room- and high-temperature-mechanical properties.

In the full-hard condition the yield strength of the steels covered is in excess of 150,000 p.s.i. (67 t.s.i. : 105 kg./mm.^{2}) and their ductility is in the region of 10 per cent. In the extra-hard condition yield strengths are of the order of 200,000 p.s.i. (89 t.s.i. : 140 kg./mm.^{2}) and ductility ranges from 1 to 5 per cent. Good strength properties are retained up to temperatures in the range 1000°–1200°F. (540°–650°C.).

Stainless-Steel Wire, Rivets and Split Pins

MINISTRY OF AVIATION: 'Chromium-Nickel Corrosion-Resistant Steel Wire, Rivets and Split Pins.'

Aircraft Material Specification D.T.D. 189*A*, 1959. Price 6d.

The first section of the specification lays down general requirements with respect to the manufacture and inspection of steel (within the following composition range) used for the manufacture of corrosion-resisting wire: carbon 0·15 max., silicon 0·2 min., manganese 2 max., sulphur 0·045 max., phosphorus 0·045 max., chromium 17–20, nickel 7–10 (nickel + chromium 25 min.), titanium 4 × C or niobium 8 × C, per cent. Section two covers the manufacture, condition and testing of such wire. The last section relates to the manufacture of rivets and split pins from wire conforming to the requirements of section two.

Summary of British and Foreign Specifications for Steel Castings

See abstract on p. 1.

Nickel-base Alloys and Stainless Steel: Literature Reviews

Industrial and Engineering Chemistry of Sept. 1959, vol. 50, No. 9, Part II, contains The Twelfth Annual Review of Unit Processes in Chemical Engineering.

As in earlier reviews, the articles are based on the literature which has appeared since the previous surveys. Two items in the section on materials of construction are of specific interest in relation to nickel-containing alloys and steels. Their scope is indicated below.

A. J. MARRON: 'Nickel and High-Nickel Alloys', pp. 1197–1203.

The review (based on a *bibliography* of 139 items) is in

six main sections, covering, respectively: applications in the chemical and process industries; high-temperature properties and applications; electronic applications; miscellaneous applications; developments in nickel plating; and fabrication, welding and brazing.

W. H. LUCE and J. H. PEACOCK: 'Stainless Steels and Other Ferrous Alloys', pp. 1215–22.

The review opens with a survey of literature on intergranular, stress and pitting corrosion of stainless steels. Literature cited in relation to mechanical properties includes reports of investigations on precipitation-hardenable stainless steels, stress-relief treatment and the effects of irradiation. Papers presenting the findings of structural studies are discussed, and the considerable attention devoted to the evaluation of high-temperature materials is reflected in the large number of reports referred to in the section reviewing high-temperature properties and applications. In a survey of recent developments in welding, allusions are made not only to investigations of the general welding characteristics of the austenitic stainless steels, but also to procedures found suitable for specific applications. In subsequent sections the results of work on the production, working and surface-treatment of stainless steels are summarised, and the final section covers literature on miscellaneous iron-base materials.

Metallurgical Factors Influencing Stress-Corrosion Cracking of Austenitic Stainless Steels

H. H. UHLIG and R. A. WHITE: 'Some Metallurgical Factors Affecting Stress-Corrosion Cracking of Austenitic Stainless Steels.'

Amer. Soc. Metals, 1959, *Preprint* 167; 18 pp.

In the investigation reported, which was carried out in an attempt to throw light on the metallurgical factors involved in stress-corrosion cracking of austenitic steels, steels of the following types were exposed, under stress, to a boiling 42 per cent. $MgCl_2$ solution: (1) 18–8 chromium–nickel steels, which, on quenching from elevated temperatures or on cold-working, transform in part to ferrite; (2) 20–20 chromium–nickel steels which remain austenitic after quenching or cold working. Both commercially-produced grades and laboratory vacuum-melted heats of steel were studied.

Before testing, the steels, in the form of sheet, were either annealed at 1050°C., water-quenched and then sheared to size, or sheared first and then annealed. The specimens were prepared for testing by being bent, beyond the elastic limit, to a 'C'-shape. The span of the specimens was then adjusted to, and held at, a given dimension, so that each was subjected to a specific degree of plastic deformation and was under continuous and relatively constant load. In general, the steels were exposed to the test environment for 200–250 hours, time to cracking being recorded electrically. In the main series of tests the specimens were bent to the required span at room temperature, but a few experiments were conducted on specimens of commercial 18–8 Type 304 stainless steel which had been bent at temperatures below or above room temperature, annealed, sheared to size and finally stress-relieved before testing.

The influence, on susceptibility to stress-corrosion cracking, of the following variables was studied: nitrogen and carbon content of the specimen, niobium and titanium content, silicon content, cobalt content, boron content, and the temperature at which the specimen was stressed (i.e., in the range −196°C. to +400°C.). Data pertaining to each of the variables investigated are tabulated.

The results obtained show that the stainless steels with low carbon or nitrogen contents did not fail within the maximum time of exposure, though commercial Type 304 steels failed within 0·2–1·4 hours. Stable austenitic steels of 20–20 type exhibited a similar resistance to cracking, provided their nitrogen content was sufficiently low (i.e., in the region of 0·002 per cent.), and, in contrast to its effect on 18–8 steel, carbon was in this case found to confer resistance to cracking.

Niobium present in 18–8 steels with low nitrogen and carbon contents stabilised the γ-phase on quenching from 1050°C., and the steel was shown to be susceptible to cracking in the as-quenched condition. Titanium, on the other hand, neither stabilised the γ-phase nor induced susceptibility to cracking. Re-melted commercial Type 304 stainless steel alloyed with titanium or niobium cracked in about the same short time as commercial Type 304, 321 or 347 steels, a finding which is considered to indicate that the two elements have little or no influence on cracking in commercial compositions.

Silicon considerably increased the resistance of 18–8 steel to cracking, and had a similar effect on commercial 25–20 steels (Type 310). The presence of cobalt, and probably also of boron, was beneficial.

Bending the specimens at temperatures higher than room temperature had no effect on susceptibility to cracking, but for specimens stressed at temperatures below 0°C. the time to cracking increased as the temperature was lowered. The average cracking time for specimens bent at the temperature of liquid nitrogen (−196°C.) was five times longer than that for specimens bent at room temperature. The final anneal to which sheared-and-annealed specimens were subjected eliminated the effects of the cold worked edges, and bending at −196°C. produced complete resistance to cracking within the duration of the test programme.

It is concluded from these findings that α-phase 18–8 steel is relatively resistant to stress-corrosion cracking, irrespective of whether the cracking is induced by transformation on quenching from 1050°C. or by cold-working at or below room temperature. Austenitic 18–8 steel, on the other hand, readily fails by cracking irrespective of whether the γ-phase was stabilised by nitrogen, carbon or niobium.

The mechanism of cracking appeared to involve the formation of crack-sensitive paths by plastic deformation. Nitrogen, in particular, diffuses to lattice-imperfection sites, such as dislocations, and forms cathodic areas. The beneficial effect of silicon and nickel is considered to be due to their altering the pattern, or inhibiting the formation, of cathodic atmospheres or precipitates.

Effect of Partial Immersion on the Corrosion of Galvanic Couples

P. HERSCH: 'Partly-Wetted Galvanic Corrosion Couples.'

Corrosion Technology, 1959, vol. 6, Oct., pp. 293–5.

To determine the influence, on the corrosion of galvanic couples, of partial immersion of one of the components, the following experiments were carried out: (1) Using the system nickel/electrolyte/mild-steel wool, current readings were taken over a period of about 24 hours. The nickel, which comprised the cathode, was completely submerged in the electrolyte or emerged to a height of about 2 mm. above the meniscus. The steel wool was in all cases completely submerged. The electrolytes used were 1*M* solutions of alkali and ammonium halides, thiocyanate, azide, sulphate, monohydrogenphosphate, dihydrogenphosphate, nitrate and nitrite. (2) A study was made of the effect of adding bivalent metal sulphates (magnesium, manganese, iron and cobalt) to the system nickel/1*M*$(NH_4)_2SO_4$/steel wool, the nickel emerging to a height of 5 mm. above the surface of the electrolyte. (3) Using nickel or silver or 18-8-Nb steel as the cathode (the emerging height being 5 mm.), current readings were taken over periods of 5 to 12 days. (4) A study was made of the effect of electrolyte concentration on the system Ni/NaCl/steel wool. Full details are given of the apparatus and procedures used and of the results obtained.

When the nickel cathode emerged only 2 mm. from the surface the corrosion rate was several times that determined when the couple was completely submerged. As expected, the addition of magnesium salts lowered the corrosion rate, due to the precipitation of hydroxide at the meniscus (the locus of the electro-reduction of oxygen), but the addition of ions of the transition metals did not, as was anticipated, offset this effect, and all three ions also lowered the corrosion rate. The relative potency of the three cathodes studied in dilute NaCl solutions was: Ag>Ni> stainless steel (and this result, which showed that the conductivity of the electrolyte was not a rate-determining factor, was observed for all the sodium salts examined). When the sodium was replaced by ammonium ions (in the ammonium-salt tests), nickel became more potent as an oxygen cathode than silver; the activity of stainless steel as a cathode was not, however, significantly enhanced by this solution change.

For a galvanic couple fully submerged in an electrolyte, the rate of corrosion of the anodic partner is roughly proportional to the combined areas of both metals, and is independent of the ratio of the single areas exposed.

Symposium on Atmospheric Corrosion

Corrosion, 1959, vol. 15, Oct., pp. 523t–45t, contains a series of educational lectures which, concerned with the fundamental aspects of atmospheric corrosion, were presented at the 1958 meeting of the National Association of Corrosion Engineers, San Francisco. The scope of the four papers is indicated in the abstracts below.

Atmospheric Corrosion of Ferrous Materials

C. P. LARRABEE: 'Mechanisms by which Ferrous Metals Corrode in the Atmosphere', pp. 526t–29t.

After reference to the various theories which have been advanced to explain the corrosion of metals, the author briefly outlines the basic principles of the now generally accepted electrochemical theory of corrosion, and, in this context, discusses the mechanism of atmospheric corrosion of iron and steel. The corrosion-resistance conferred by surface oxide films is discussed, and the influence, on the protective capacity of the film, of alloying additions, and of corrosives present on the surface or in the atmosphere, is illustrated by data on carbon, low-alloy and stainless steels. The variables governing the progress of corrosion after initiation of rusting are reviewed, and attention is directed to work aimed at determining the mechanism underlying the protective capacity of certain rust films.

Atmospheric Corrosion of Non-Ferrous Metals

P. M. AZIZ and H. P. GODARD: 'Mechanism by which Non-Ferrous Metals Corrode in the Atmosphere', pp. 529–33t.

In this review of literature relating to the mechanism involved in atmospheric corrosion of non-ferrous metals, particular emphasis is placed on the results of work carried out, under the aegis of The British Non-Ferrous Metals Research Association, by Vernon, Hudson, *et al.*, over the period 1925 to the present time.

An outline is given of the processes underlying atmospheric corrosion, and reference is made to the influence of 'promoting' factors (pollutants, such as sulphides, commonly present in the atmosphere), and 'controlling' factors (such as the water vapour present in the atmosphere). The severity of atmospheric corrosion will, in general, vary with the relative humidity, the extent of industrial pollution, and the general atmospheric conditions prevailing in a given locale. Consideration of these factors is followed in the second part of the paper by a critical survey of published work on the reactions involved in atmospheric corrosion of nickel, copper, zinc, aluminium and magnesium.

On the basis of the literature reviewed the authors make the following generalisations:

'The atmospheric corrosion of non-ferrous metals

depends primarily on the presence of moisture and certain atmospheric pollutants. Atmospheric water vapour, rain, dew or mists will result in the formation of adsorbed or liquid films of moisture on the surface of the metal which can absorb pollutants from the atmosphere, with the production of a corrosive solution. In the absence of liquid water, a critical relative humidity must in general be exceeded before attack proceeds. In industrial environments the most important pollutant is sulphur dioxide, which is oxidised catalytically to the trioxide, and which can then form sulphuric acid, with subsequent attack on the metal surface. In the case of certain metals, such as magnesium and zinc, carbon dioxide also can play a rôle. In marine atmosphere, air-borne salt or saline spray from the sea can provide the corrosive medium.'

Design and Interpretation of Atmospheric-Corrosion Tests

H. R. COPSON: 'Design and Interpretation of Atmospheric Corrosion Tests', pp. 533t–41t.

The purpose of the paper is 'to review what has been learnt about atmospheric-corrosion testing, in the hope that this will prove useful in the design and interpretation of new atmospheric-corrosion-test programmes'.

The review may be divided into seven sections. In the first the author briefly discusses the principles involved in atmospheric-corrosion testing. The problem of determining the test locale is then considered, and, in this connection, attention is drawn to the inherent difficulty of classifying a particular atmospheric environment, and to the fact that different atmospheric environments vary in the degree to which they attack different metals. The main conclusion is that tests should be carried out in as many locales as possible, and, at least, in marine, industrial, and rural or suburban atmospheres. Methods of mounting the specimens after determination of the test site are covered in some detail in the third section of the paper. The advantages and limitations of the various mounting techniques are discussed in relation to such factors as crevices, drainage, size and shape of the specimen, use of shelters, and the desirability of exposing the specimens under conditions closely simulating those of service. Means of assessing the reproducibility of atmospheric-corrosion tests are considered in the fourth section, while in the fifth and sixth sections tentative answers are given to the questions of how long the tests should be continued, and whether atmospheric-corrosion tests can be replaced by accelerated-corrosion tests. The paper ends with a review of the problems involved in evaluating the results of atmospheric-corrosion tests.

The points raised in the review are supplemented throughout by reference to photographs and diagrams, and to data on the atmospheric corrosion of various materials, including nickel, and nickel-containing low-alloy and stainless steels.

Deterioration of Materials due to Air Pollution

J. E. YOCOM: 'Deterioration of Materials in Polluted Atmospheres', pp. 541t–5t.

The author's main concern is with the examination of the effects of specific air pollutants known to cause deterioration of materials. Discussion in this respect is introduced by a brief survey of the types of pollutant commonly present in the atmosphere, of the factors which contribute to the concentration of such pollution, and of the effects of topography and 'temperature inversion'.

The influence of the following pollutants is considered: carbon dioxide, hydrogen sulphide, hydrogen fluoride, ozone and photo-chemical smog, and solid particles. Reference is made to the principal sources of these pollutants and to the mechanisms by which they attack such materials as metals, building materials, leather, paper, paint, rubber and elastomers, and textiles and dyes.

Corrosion of Nickel and 'Inconel' in a Fused-Salt Environment

W. D. MANLY: 'Dynamic Corrosion Screening Tests on 'Inconel' and Nickel in $NaCl$-$MgCl_2$-UCl_3 Bath.' *U.S. Atomic Energy Commission, Report ORNL* 57-6-72, 1959; 8 pp.

To obtain data in connection with development work on a fused-salt fast-breeder reactor, dynamic corrosion tests were carried out, using two tilting furnaces, on 'Inconel' and nickel capsules containing the relevant fluid-fuel environment (50-33·3-16·7 mole per cent. $NaCl$-$MgCl_2$-UCl_3).

In one furnace the tests, which were continued for 100 hours, involved exposure to a hot-zone temperature of 1800°F. (980°C.), the temperature gradient between the hot and cold zones being 320F°. (178C°.). In the second furnace the capsules were exposed for 500 hours; the temperature of the hot zone was 1350°F. (735°C.) and the temperature gradient 280F°. (155C°.). The capsules were cycled once every minute.

In the 100-hour tests nickel was found to be more susceptible to mass transfer than 'Inconel', but suffered no transfer in the 500-hour test although 'Inconel' showed some signs of attack under the same conditions. These results are considered to indicate that nickel would be more satisfactory than 'Inconel' as a container for the relevant chloride bath at temperatures in the region of 1350 F. (735 °C.), and that selective leaching of chromium from 'Inconel' is more severe at 1800°F. (980°C.) than in a 500-hour test at a lower temperature.

Corrosion Experience Gained in Hydrometallurgical Refining of Nickel

R. B. MCINTOSH: 'Corrosion Experience Associated with Hydrometallurgical Refining of Nickel at Sherritt Gordon Mines.'

Corrosion, 1959, vol. 15, Oct., pp. 547t–53t.

Laboratory work carried out by Sherritt Gordon Mines, Ltd., in 1949 having confirmed the feasibility

of using a novel hydrometallurgical process to refine nickel-sulphide concentrates produced, by conventional flotation techniques, from ore at Lynn Lake, Manitoba, a pilot-plant was operated from 1949 to 1954 to evaluate the suitability of various materials of construction for the equipment used in the stages comprising the process. (For an account of the Sherritt Gordon ammonia-leach process see, *inter alia*, paper by FORWARD and MACKIW referred to in *Nickel Bulletin*, 1955, vol. 28, No. 5, p. 83.) The purpose of the present paper is to compare the conclusions drawn from this pilot-plant study with those drawn from experience gained in refinery operation over a period of four years.

The information discussed relates to mild steel and to 18-8, niobium-stabilised 18-8, 18-8-Mo, and extra-low-carbon 18-8-Mo grades of chromium-nickel stainless steels (Types 304, 347, 316 and 316L). The comparison of pilot-plant and refinery experience is made in sections concerned with equipment used in the leach and filtration circuits, the copper-removal circuit, and the nickel-reduction circuit. Supplementary to this comparison, corrosion problems encountered in stainless-steel components of the reduction autoclaves and the copper-liquor regenerator are described in some detail.

Materials of Construction for Urea-Synthesis Plants

I. WILENITZ: 'Materials of Construction for Urea Plants.'

Petroleum Refiner, 1959, vol. 38, Oct., pp. 98–106.

In this article the author reviews the suitability of various materials for use in plants synthesising urea from ammonia and carbon dioxide. The review is based on experience with the Pechiney-Grace process, and, although much of the information presented is considered generally applicable to other processes, this fact is emphasised.

A study of the published literature disclosed that the data available on plant (as opposed to experimental) conditions were sparse. Reference is, however, made to a table, drawn up by the Tennessee Valley Authority as a result of an extensive literature survey, which lists corrosion rates for various ferrous and non-ferrous materials (including nickel and various nickel-containing stainless steels) exposed to chemical systems approximating to urea-autoclave conditions. The presence of oxygen, and the quantities in which it is present, can have a very important bearing on the corrosion-resistance of the materials used in urea-synthesis plants, and the influence of oxygen, and that of excess carbon dioxide in the synthesis system, another important factor in relation to corrosion resistance, are discussed.

In the main section of the paper an attempt is made to evaluate the suitability of various materials for use in such equipment as the autoclave, decomposer, reactor, salt-oil pumps, salt-oil heater, decanter, absorber and stripper. Three groups of material are evaluated: ferrous materials and nickel and its alloys; non-ferrous metals and alloys; and non-metallic materials.

The ferrous group is sub-divided in the paper into carbon steel and stainless and high-alloy steels, and, in discussing these materials, the author refers to corrosion data tabulated for Types 304L, 316, 317 and 347 chromium-nickel stainless steel exposed in various locations of a urea plant. Consideration of these data leads the author to suggest that in the Pechiney-Grace process high-alloy and stainless steels should be used only at temperatures below 275°F. (135°C.). The corrosion-resistance of such steels is listed (in descending order of corrosion-resistance) as follows: 20-10 chromium-nickel steel (Type 309); stabilised 18-8 Mo; unstabilised 18-8 Mo (e.g., Types 316 and 317); extra-low-carbon 18-8 steel (Type 304L).

Little reference is made in the literature to the performance of nickel and its alloys in urea synthesis. In the present review the discussion is based on corrosion data presented for nickel, 'Monel', and eight Ni-Cr-(Co)-Fe-base alloys used for components of the reactor, autoclave and decomposer of an operating plant. The performance of each of these materials and the applications for which they are considered suitable are noted.

Of the two other classes of material examined in the paper, the non-ferrous group is discussed in sections concerned with aluminium and its alloys, copper and its alloys, aluminium-bronze, lead, titanium and tungsten. Ceramics, paint, glass, carbon and graphite, and phenolic resins comprise the third, non-metallic, group reviewed by the author.

Materials Used in Railroad Tank Cars

C. T. GRAVES: 'Materials Used in Railroad Tank Cars.'

Amer. Soc. Mechanical Engineers, 1959, *Paper* 59-*PET*-5; 4 pp.

In the U.S.A. a fleet of about 200,000 railroad tank cars, with a life expectancy of about 20 years, are used to transport, at pressures ranging from atmospheric to 2400 p.s.i.g., over 1500 commodities (for example, petroleum products, edibles, acids, and liquified and compressed gases). The safe transportation of these products is governed to a great extent by the materials used in the construction of the cars. Materials of interest in this respect, the applications which they find, and the factors involved in their selection, form the subjects of the present paper.

A brief review of the regulations and specifications relating to the construction and operation of tank cars is followed by a discussion of the factors to be considered in selecting materials of construction: chemical and physical properties of the commodity; methods of loading and unloading; the versatility of the tank; the availability of the materials of construction and of replacement parts. Consideration is then given to the materials commonly used for the tank, the fittings and appurtenances, the underframe and the truck of the car. Notes on painting and the use of linings and coatings end the review.

For most service conditions carbon steel (*A.S.T.M. A*-285 Grade C Flange Quality) is used for the tank shell, heads and expansion zone, but attention is drawn to the use made, when corrosion-resistance or low-temperature properties are important, of various grades of chromium-nickel stainless steel, of carbon-steel plate clad with stainless steel, and of aluminium alloys. In other sections the notes on typical materials of construction include references to the use of nickel or 18-8-type stainless steel for heater coils, and to tank linings produced by chemical deposition of nickel.

Factors Influencing the Performance of Stainless-Steel Flexible Bellows Joints

C. M. DANIELS: 'Designing for Duct Flexibility with Bellows Joints.'

Machine Design. 1959, vol. 31, Oct. 15, pp. 146-55.

Because of their high freedom of motion in axial and angular directions, metallic bellows offer, in duct applications, sufficient flexibility to compensate for thermal expansion and contraction, installation misalignment, structural deflection, and vibration. In this article, which is based on experience in the design of bellows for aircraft and missile fuel systems, the author reviews the factors which influence the selection of the most suitable type for a given application.

Both the type of configuration and the material of construction used for a specific bellows will affect the performance of the joint. The review opens therefore with a discussion of the characteristics which might be prerequisite for satisfactory service in a specific application, and of the design considerations involved in the satisfaction of these requirements. The various designs used to restrain axial expansion resulting from thrusts developed in the bellows by internal pressure are considered (the characteristics of 16 bellows joints incorporating various types of restraint being summarised in tabular form), while notes are given on the factors governing resistance to buckling, ability to deflect axially, fatigue-resistance, and resistance to torsional deflection.

Bellows are often subjected to pressures of 25-2000 p.s.i. and to temperatures ranging from −425° to +1600°F. (−255°to +870°C.), and the performance of a flexible joint under these conditions will depend not only on the design of the bellows, but also on the strength of the material of construction and its resistance to attack by the fluid to which it is exposed.

In this connexion the physical and mechanical properties of the following materials are summarised: A.I.S.I. Type 321 and 347 chromium-nickel stainless steels, 'A-286', 'AM-350', 'Inconel X', '17-7 P.H.', titanium and aluminium.

The review ends with notes on quality control and the tests used to evaluate the suitability of a bellows for a specific application: spring-rate testing, tests to determine pressure-loss characteristics, and vibration testing.

Slip-Casting of Stainless-Steel and Nickel Powders

H. H. HAUSNER: 'Slip-Casting of Metal Powders. Part III.'

U.S. Atomic Energy Commission, Report NYO-8666, Feb. 12, 1959; 36 pp.

In this report the author (1) reviews the findings of previous work carried out during a comprehensive investigation to determine the feasibility of applying slip-casting techniques to the production of components from metallic powders, and (2) summarises the results obtained in the final phase of the programme.

References are given to reports previously issued. A review of the findings contained in these reports indicates that the fundamental factors and variables involved in slip-casting metal powders have been established, that the process can be applied to the production of components larger and of more complicated shape than those obtainable by conventional powder metallurgy, and that the physical properties of slip-cast parts are superior in certain respects to those of pressure-compacted components.

Most of this work was carried out using spherical 18-8-molybdenum (Type 316) stainless-steel powders. The experiments conducted in the last phase of the investigation were initiated (1) to determine whether the slip-casting process could be applied to powders other than the spherical stainless-steel powder previously used (i.e., to irregularly shaped 18-8-molybdenum stainless-steel powder and to nickel powder); (2) to compare the properties of slip-cast and pressure-compacted spherical stainless-steel powders after various sintering treatments; and (3) to establish the influence of the concentration of ammonium alginate (the deflocculant used in the slip) on the physical properties of ammonium-alginate/water solutions.

The data presented show that slip-casting of nickel powder or irregularly shaped stainless steel is possible. Results obtained at the present stage of development are, however, only 'promising' and suggest the need for modifying the processing variables to suit the relevant metal powder, and probably even the particle size of that powder. A comparison of the sintering behaviour of slip-cast and pressure-compacted Type 316 stainless-steel powder indicates that the slip-cast material sinters at a faster rate than pressure-compacted powder. The physical properties of the sintered materials made by both methods are tabulated.

Electrolytic Etching of Stainless Steel

E. KUNZE and E. HORN: 'Development of Metallographically Etched Structures in Relation to the Amount of Metal Electrolytically Dissolved.'

Archiv f. d. Eisenhüttenwesen, 1959, vol. 30, Oct., pp. 613-17.

The experiments described were carried out in an attempt to establish the conditions necessary for reproducible results in the electrolytic etching of a variety of commercial low-, medium-, and high-alloy steels.

For given conditions of anodic reaction and a given surface area, the amount of metal removed from the specimen is governed by the amount of current used. Consequently the intensity of the etch can be determined in terms of the current used per unit area of surface and can be expressed in Coulomb/cm.^{2}. The metallographer is thus in a position correctly to determine the intensity of the etch without interference from the variables involved in usual etching techniques and irrespective of the type of specimen being examined.

Details are given of the apparatus used and the conditions established for electrolytic etching of various grades of alloy steel (including those of 18-8 chromium-nickel type) in various conditions of heat-treatment. The quantity of metal required to be dissolved for development of a satisfactory microstructure was found to depend on the condition of heat-treatment of the specimen and the distribution and fineness of the phases present, and it was therefore possible to determine, by measuring the current used during etching, the heat-treatments to which the specimens had been subjected prior to etching.

The following electrolytes were found suitable for use with the steels listed:

Low-alloy steels: sodium acetate + Zephirol.

Medium-alloy steels: 0·1 per cent. alcoholic aqueous hydrochloric acid.

High-alloy steels: 3 per cent. alcoholic hydrochloric acid.

The solutions should not contain any free acid.

Determination of Aluminium in High-Temperature Alloys

K. L. CHENG and F. J. WARMUTH: 'Determination of Aluminium in High-Temperature Alloys.'

Chemist-Analyst, 1959 vol. 48, Sept., pp. 74–6.

The determination of aluminium in high-temperature alloys by the gravimetric phosphate method involves a long and tedious procedure. The present paper gives details of a technique developed for determination of the metal in complex high-temperature alloys containing many interfering metals, in which EDTA titration, employing PAN as indicator, is applied after mercury-cathode and cupferron separations. When niobium and tantalum are present, co-precipitation of aluminium occurs upon digestion of the sample, and the procedure must be adjusted to recover this aluminium. The EDTA titration technique is recommended for alloys containing more than 1 per cent. aluminium; for alloys low in aluminium a colorimetric approach is considered preferable.

Procedures established for determination of aluminium in the following nickel-base alloys are described, and representative results are compared with those obtained by the phosphate technique: 'Waspaloy', 'NBS 169', 'M-252', 'René 41' and 'Inco 713'.

Spectrographic Determination of Tantalum and Niobium in Stainless Steels

M. NEUILLY: 'Spectrographic Determination of Tantalum and Niobium in 18–8-type Stainless Steels.'

Mémoires Scientifiques de la Revue de Métallurgie, 1959, vol. 56, Oct., pp. 484–9; disc., pp. 489–90.

The work described was carried out in view of the restrictions imposed on steels containing tantalum by certain specifications covering the use of structural materials in atomic energy applications. Niobium-stabilised chromium-nickel steels generally contain trace amounts of tantalum introduced, as an impurity, via the ferro-niobium addition, and the work described was conducted to develop a method capable of permitting determination of the metal in such steels with greater accuracy than that obtainable by chemical analysis.

In the method finally adopted the tantalum and niobium after chemical separation, are determined spectrographically using a Feussner spark source and a medium-dispersion spectrograph. The specimens are compared with synthetic standards. The author's experiments show that for tantalum contents in the range 0·03–0·24 per cent. the values obtained are accurate to ±0·01 per cent.

Resistance-Welding of Nickel-containing Materials

K. H. MCDOWELL and D. A. WEEKS: 'A Practical Approach to Resistance Welding.'

British Welding Jnl., 1959, vol. 6, Sept., pp. 381–95.

In recent years the techniques and equipment used in resistance welding have been developed to a degree which has rendered the process an indispensible tool in the manufacture of sheet-metal products. The main purpose of the present paper is to review the factors which must be taken into account if optimum results are to be obtained, and, in particular, to examine the practical aspects of resistance welding with emphasis on its use in the gas-turbine industry.

The review is in five sections, in the first of which the basic principles of resistance welding are briefly outlined. In the second section details are given of the various machines and processes used in the gas-turbine industry (i.e., spotwelding, tackwelding, stitchwelding, seamwelding, projection welding and butt welding), and the factors governing choice of suitable welding machines are discussed. It is pointed out that care must be taken to ensure that the design of the component lends itself to effective resistance welding, and design considerations form the subject of the third section. The metallurgical factors involved in resistance welding are briefly noted in the next section, and the problems to which they give rise are exemplified in subsections in which the author draws attention to the precautions necessary in welding light alloys, carbon and low-alloy steels, martensitic, austenitic and heat-resisting stainless

steels, nickel-base high-temperature alloys, titanium, coated materials and dissimilar metals. The information given in this connection is supplemented by photomacro- and photomicrographs of welds produced in the materials discussed, and by tabulated data indicating the quality of welds (if welding is feasible) produced between any two of the following materials: aluminium and its alloys, mild steel, stainless steels, nickel and its alloys, brass, copper, magnesium and its alloys, plated mild steel, titanium, and phosphor-bronze. The paper ends with a review of the methods used to ensure control of quality in resistance welds (i.e., visual examination, tensile shear tests, macro-examination, peel or chipping tests, twist tests, and 'pillow' pressure tests).

Welding of Dissimilar Metals by the Metallic-Arc Process

J. HINDE: 'The Welding of Dissimilar Metals by the Metallic-Arc Process.'

HENRY WIGGIN & CO., LTD., *Publn.* 1929*, Nov. 1959; 27 pp.

In this review of the factors involved in metallic-arc welding of dissimilar materials the author is concerned mainly with consideration of the metallurgical variables pertaining to, and the electrodes and processes most suitable for, joining combinations of the following materials (the physical and mechanical properties of which are tabulated): 'AT nickel'; 'Monel'; 'Inconel'; 'Corronel 210'; 'Corronel 220'; 25-20, 25-12 and 18-8 chromium-nickel austenitic stainless steels; chromium stainless steels; low-alloy steels; mild steels.

The economic considerations conducive to the use of a combination of dissimilar materials are noted, and the factors governing the choice of electrodes for joining such materials are considered. In the latter connection, the significance of weld-metal dilution is discussed in relation to compatible, incompatible and partially-compatible combinations. Ways of controlling weld-metal dilution in metallic-arc welding are mentioned.

This general introduction is followed by sections outlining the metallurgical problems associated with, and the procedures and electrodes suitable for, metallic-arc welding the high-nickel alloys and the austenitic stainless steels to dissimilar materials. Subjects discussed in these two sections include 'buttering', the heat-affected zone, the use of the Schaeffler diagram, prevention of carbide migration, and welding of steels used in low-temperature applications. The information is supplemented by tables indicating electrodes suitable for welding various combinations of the materials discussed, giving typical compositions of weld deposits produced with such electrodes, and illustrating the mechanical properties obtainable in welds produced using 'Inco-Weld A' electrodes.

The review ends with a survey of the procedures employed to overlay and apply linings to steel and of those used to weld clad steel.

* *We shall be pleased to supply a free copy of this publication.*

The Welding of '17-4 P.H.' Stainless Steel

G. E. LINNERT: 'Procedures for Welding '17-4 P.H.' Stainless Steel.'

Welding Engineer, 1959, vol. 44, Nov., pp. 38-40.

The precipitation - hardenable chromium - nickel stainless steel '17-4 P.H.' exhibits satisfactory weldability under production conditions and has been used for a variety of welded assemblies incorporating sections ranging from small machined fittings to heavy members prepared from blooms, bars or forgings. Using correct welding practice, sound joints are easily achieved, and properties comparable to those of the basis metal can be obtained by subsequent heat-treatment. In this article the author describes the welding practice which experience has shown to produce optimum results.

Any arc- or resistance-welding technique suitable for the standard austenitic grades of stainless steel is considered applicable to '17-4 P.H.', and metal-arc-, tungsten-inert-gas-, and resistance-welding procedures do not differ from those associated with the austenitic grades. As filler metal, use may be made, depending on the properties required, of '17-4 P.H.' or austenitic steel (e.g., Type 308). Data are tabulated illustrating the mechanical properties obtainable in solution-treated-and-hardened weld metal and in metal-arc-welded joints in the as-welded condition and after various heat-treatments.

Post-weld heat-treatment is discussed, and a note is included on torch cutting.

Induction Brazing and Soldering

See abstract on p. 2.

Production of Raised Studs on Metal Surfaces by Spot Welding

See abstract on p. 1.

ANALYSIS

Chemical Determination of Alloying or Contaminant Elements in Electronic Nickel

See abstract on p. 4.

Determination of Nickel in Nickel-Iron Alloys

See abstract on p. 5.

Determination of Nickel in Steel and Cast Iron

See abstract on p. 5.

Simultaneous Spectrophotometric Determination of Copper and Nickel in Low-Alloy Steel

See abstract on p. 11.

Determination of Aluminium in High-Temperature Alloys

See abstract on p. 31.

Spectrographic Determination of Tantalum and Niobium in Stainless Steels

See abstract on p. 31.

PATENTS

Zone Refining of Nickel

A rod of a refractory material which is stable when molten is mounted in an evacuated chamber and zone melted by bombarding a narrow zone of the rod with electrons. Zone refining is effected either by traversing the rod past the cathode or conversely by fixing the rod and traversing the cathode. The concentrated heating which results melts the rod, but the electron bombardment is confined to a zone so limited that the molten material is held to the unmelted portions by surface tension.

The application of the invention to vacuum coating, de-gassing and the production of single crystals is specifically claimed. Metals which may be treated by the process include nickel, tungsten, tantalum, rhenium, molybdenum, vanadium, platinum, silicon and ruthenium.

NATIONAL RESEARCH DEVELOPMENT CORPORATION (inventors, M. DAVIS and R. F. LEVER). *Brit. Pat.* 826,132.

Continuous Production of Strip from Nickel Powder

Metal powder is formed into a continuous compact, suitable for sintering to strip, by passage through a gap between a pair of rolls. Air at the roll gap is replaced by a gas of lower viscosity (preferably hydrogen) the pressure of which is maintained above atmospheric around the gap. The rolling speed is greater than that at which the maximum thickness without laminar cracking is obtainable under otherwise corresponding rolling conditions.

The invention is particularly applicable to the production of metal strip from powders of low bulk density, e.g., carbonyl-nickel powders of fibrous structure.

MOND NICKEL COMPANY, LTD. (inventor, D. K. WORN). *Brit. Pat.* 825,953.

Nickel-containing Fungicides for Prevention and Eradication of Rust in Plants

The inventors claim a process which is stated to prevent or eradicate rust infection without substantial phytotoxic damage to the infected plant. The plant is treated with nickel compounds which, when applied in appropriate amounts (i.e., sufficient to ensure a nickel distribution of 0·02–4 lb. (9–1000 gm.) per acre) eradicates, and prevents further onset of, rust.

The types of nickel compound covered, suitable adherents and surface-active agents, and methods of applying the fungicides are outlined in the preamble to the patent. Details are given also of greenhouse and field trials.

ROHM AND HAAS COMPANY, assignees of H. L. KEIL and H. P. FROHLICH. *South African Pat.* 194/59.

Durable Coating Compositions containing Basic Nickel Carbonate

The coating composition comprises an organic film-forming material and sufficient basic nickel carbonate to impart durability to the coating. The basic nickel carbonate, which is preferably present in an amount equal to 0·3–50 parts per 100 parts by weight of film-forming material, contains nickel carbonate 50–60, nickel hydroxide 20–30, per cent., remainder water. The organic film-forming material consists of an alkyd resin, cellulose nitrate, or an oleoresinous varnish. The coating composition preferably contains also a coloured pigment (e.g., a nickel complex of an azo dye).

The use of basic nickel carbonate in coloured finishes is stated not only to confer increased durability, but also to offer financial advantages, since it can replace a substantial part of the more expensive coloured durable pigment used in the production of such coatings.

J. JACKSON, assignor to E. I. DU PONT DE NEMOURS AND COMPANY. *U.S. Pat.* 2,913,348.

Manufacture of Cadmium Plates for Nickel/Cadmium Batteries

Cadmium plates for nickel/cadmium batteries are manufactured by impregnating sintered nickel plaques in a cadmium-salt solution containing 1 gm./L. of polyethylene glycol, subjecting the soaked plates to cathodic polarisation in alkali solution, and finally washing and drying. Preferably the plaques are impregnated in a cadmium-nitrate solution containing about 26·5 per cent. of cadmium and about 1 gm./L. of polyethylene glycol of an average molecular weight of 6000.

Addition of polyethylene glycol is stated to reduce the tendency of the cadmium-nitrate solution to dissolve some of the nickel from the sintered plaque.

A. FLEISCHER, assignor to the U.S. SECRETARY OF THE ARMY. *U.S. Pat.* 2,899,480.

Recovery of Nickel from Alloy-Steel Grinding Dust

Metals (in particular, nickel and cobalt) which are difficult to oxidise are recovered from alloy-steel waste products (grinding dust and machine turnings and chips) by mixing the waste products with mill scale from the steels or with oxide-bearing ores (e.g., laterite and serpentine) and melting at steel-making temperatures. The mill scale or ore provides the oxygen required for oxidation of the readily oxidisable elements of the waste products. When oxidised, they pass into the slag, leaving a molten alloy of iron and nickel (or cobalt) which may then be drawn off.

C. W. SCHOTT, assignor to CRUCIBLE STEEL COMPANY OF AMERICA. *U.S. Pat.* 2,902,359.

Upgrading of Petroleum Fractions

Petroleum fractions containing aromatic and sulphur compounds, and boiling in the range 300°–650°F.

(150°–345°C.), are upgraded by a process which involves, in a first stage, their desulphurisation (preferably employing a cobalt-molybdate catalyst in the presence of hydrogen) to a maximum sulphur level of 20 parts per million by weight, and then their hydrogenation over a nickel catalyst, maintaining hydrogen rates in excess of 2000 standard cubic feet per barrel.

ESSO RESEARCH AND ENGINEERING COMPANY.
Brit. Pat. 824,635.

Electrodeposition of Black-Nickel Coatings

An aqueous acidic plating solution for electrodeposition, over a wide range of operating conditions, of black-nickel deposits falls within the following limits of composition (g./L.): nickel chloride (calculated as the hexahydrate) 50 min., ammonium chloride 7·5-45, sodium thiocyanate 7·5-30, zinc chloride 15-60. The nickel-chloride concentration is related to the current density in a graph included in the patent. The solution is operated at a pH in the range 2·3–5·5.

The adhesion and abrasion-resistance of the coatings is improved by pre-plating the surface of the article with an initial electrodeposit; preferably, a nickel electrodeposit produced from a solution containing (g./L.): boric acid 35 max., hydrochloric acid 40 max., nickel chloride (calculated as the hexahydrate) 150–340, the article being treated first anodically and then cathodically.

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 825,031.
Similar to *U.S.* „ 2,844,530.

Electroless Nickel-Plating Solution

An improved aqueous nickel-plating solution of the nickel-cation/hypophosphite-anion type contains nickel ions, 0·15–1·2 mole/L. of hypophosphite ions, and 0·25–0·6 mole/L. of lactic anions, the ratio of nickel ions to hypophosphite ions being in the range 0·25–1·6. The pH of the solution falls in the range 4·0–5·6. The solution may contain also 0·025–0·06 mole/L. of a simple short-chain saturated aliphatic monocarboxylic acid containing 3–5 carbon atoms (preferably propionic acid) and/or a salt thereof.

The solution permits plating to be carried out under stabler conditions, and the introduction of lactic-acid and/or one of its salts completely complexes all of the nickel cations and substantially increases the plating rate. The adhesion and appearance of the nickel deposits is stated to be excellent.

GENERAL AMERICAN TRANSPORTATION CORPORATION.
Brit. Pat. 821,763.
Similar to *U.S. Pats.* 2,822,293–4.
„ „ *South African Pat.* 4020/55.
„ „ *Belgian Pat.* 543,851.

Chemical Deposition of Nickel-Boron and Cobalt-Boron Alloys

Hard, corrosion- and wear-resistant coatings of nickel-boron and cobalt-boron alloys are obtained on the following metals by chemical deposition of the alloys from an aqueous alkaline solution: nickel, cobalt, steel, aluminium, zinc, palladium, platinum, copper, brass, manganese, chromium, molybdenum, tungsten, titanium, tin, silver, carbon or graphite.

The plating solution contains: a nickel or cobalt salt (preferably nickel chloride or sulphate or copper chloride) 0·02–0·2 mole/L.; a sequestering agent (e.g., ammonia) or an organic complexing agent containing amino, carboxyl or hydroxyl groups 1–10 mole per mole of salt; an alkaline metal borohydride 0·005–0·04 mole/L.

The cobalt content of the alloys is in the range 4·5–7 wt. per cent.

E. I. DU PONT DE NEMOURS AND COMPANY (inventor, T. BERZINS). *French Pat.* 1,977,797.

Production of Nickel-Phosphorus Alloys from Spent Plating Solutions

A chemical nickel-plating solution of the nickel-cation/hypophosphite-anion type becomes 'spent' when the phosphite-anion concentration approaches the threshold of insolubility of nickel phosphite and must then be discarded. Normally the solution is treated to induce random decomposition, and the nickel content of the metallic precipitate present in the residue is then recovered by smelting operations, the phosphorus content being rejected as an impurity. According to the present invention, after the 'spent' solution is treated to induce random decomposition, the metallic precipitate (containing 88–94 per cent. nickel, 6–12 per cent. phosphorus) suspended in the liquid residue is separated, melted by heating, and finally cooled to produce a nickel-phosphorus alloy with a eutectic composition nickel 89, phosphorus 11, wt. per cent., and a eutectic temperature of about 880°C.

Use of the alloys as diffusion coatings in the cladding of metals is described in the patent.

W. J. CREHAN, W. F. KLOUSE and P. TALMEY, assignors to GENERAL AMERICAN TRANSPORTATION CORPORATION.
U.S. Pat. 2,908,568.

Gas Plating of Uranium

The corrosion-resistance of uranium is improved by deposition of an adherent protective metallic coating which forms an alloy with the basis uranium at the uranium/coating interface. The metallic coating is deposited by thermal decomposition of the relevant metal carbonyl, and alloying is effected by heating to achieve a diffusion bond. The preferred coating material is chromium or nickel: the nickel coating can, according to the claims of the patent, then also serve as a carrier for a final coating of molybdenum.

In plating the uranium with molybdenum the surface is first coated with nickel (by decomposition of nickel carbonyl) and the article is then subjected to heat-treatment to diffuse part of the nickel through the basis metal to form a uranium-nickel alloy. The coated article is next heated in the presence of

molybdenum carbonyl and finally part of the molybdenum so deposited is alloyed with the uranium-nickel alloy by diffusion treatment.

D. H. GURINSKY and S. STEINGISER, assignors to U.S. ATOMIC ENERGY COMMISSION. *U.S. Pat.* 2,894,320.

Nickel Plating Thin Nickel-Alloy Wire Preparatory to Soldering

A nickel-alloy wire is prepared for soldering by a procedure involving pickling in an aqueous hydrochloric-acid/nitric-acid bath, rinsing, treating anodically in an aqueous sulphuric-acid solution, and finally electroplating (preferably first with a nickel strike and then with copper).

The main application of the process is to electrical-resistance wires fabricated from an alloy containing nickel 75, chromium 20, aluminium 2·5, copper 2·5, per cent.

D. NAPIER AND SON, LTD. (inventor, F. D. WALDRON-TROWMAN). *Brit. Pat.* 825,928.

Nickel-Plated Alloy-Steel Aircraft Propellers

Alloy steels used in the fabrication of aircraft propellers do not possess satisfactory corrosion-resistance, particularly in marine atmospheres. The necessary resistance to corrosion can be conferred by electrodeposition of a layer of nickel on the steel, but the nickel coating has the undesirable effect of reducing the fatigue-resistance of the steel. According to the claims of the patent, this decrease in fatigue-resistance is reduced by applying a layer of tin 0·00009-0·0009 in. (preferably 0·0005 in.) thick before electrodeposition of the nickel coating (which is, preferably, at least 0·0005 in. thick).

MOND NICKEL COMPANY, LTD. *Brit. Pat.* 821,098.

Nickel-Copper-Alloy Compensator Elements

A compensator element of a magnetic instrument is fabricated from an alloy containing copper 6–20, manganese 7–14, per cent., remainder nickel. Silicon and carbon should not exceed 0·1 and 0·2 per cent., respectively.

Alloys of the composition covered have a substantially constant temperature coefficient of permeability over a temperature range of about 90C.°, and the value of the temperature coefficient within this range is higher than that of the 70–30-type nickel-copper alloys commonly used.

MOND NICKEL COMPANY, LTD. (inventor, C. A. CLARK). *Brit. Pat.* 822,088.

Production of Nickel-Molybdenum-Iron Magnetic Alloys

Magnetic alloys less than 1 mil thick, and having high permeability, low coercive force and rectangular-hysteresis-loop characteristics, are produced by cold-rolling an alloy containing nickel 80±2, molybdenum 4·0±0·3, per cent., remainder iron, from a hot-rolled gauge, to achieve, in the last of a series of rolling stages involving intermediate annealing, a gauge requiring a 70–85 per cent. reduction to attain the final thickness. The alloy is finally subjected to heat-treatment at 850°–975°C. in an atmosphere consisting of 75–100 vol. per cent. of hydrogen and having a dew point below −40°C. The reduced alloy is preferably wound into a toroidal coil in the presence of an anneal separator prior to the final heat-treatment.

ARMCO INTERNATIONAL CORPORATION (inventor, M. F. LITTMANN). *Brit. Pat.* 822,360. Similar to *Canad.* „ 562,593.

Copper-containing Nickel-Iron Alloys with Improved Magnetic Properties

According to the claims of the patent, alloys containing nickel 50–80, copper 1–45, molybdenum 0–10, per cent., remainder iron, are formed at 1150°–1300°C., annealed in hydrogen, and finally cooled from 600°–400°C., at a controlled rate, to produce magnetic articles having stabilised or pre-determined temperature coefficients of permeability.

The permeability of an alloy containing nickel 75·9–77·8, copper 2–5·2, molybdenum 3·8–5, manganese 0·7, silicon 0·05, per cent., remainder iron, and cooled at a rate of 30C.° / hour, is temperature-independent in the range 20°–80°C., while that of an alloy of the following composition becomes temperature-independent in the range −10° to +40°C. when the alloy is cooled at 90C.°/hour: nickel 70·8, copper 14·1, molybdenum 2·8, manganese 0·9, silicon 0·05, per cent., remainder iron.

The invention is stated to be particularly applicable to the treatment of alloys containing nickel 67–80, copper 2–20, metals of the chromium group+ vanadium 0·5–10 (but at least 0·5 of each), per cent., remainder iron.

VACUUMSCHMELZE A.G. (inventors, F. ASSMUS and F. PFEIFER). *German Pat.* 1,066,362. Addition to „ „ 867,006.

Iron-Nickel-Aluminium Permanent-Magnet Alloys Exhibiting Anisotropic Properties

The patent covers the production, from compositions hitherto regarded as capable of exhibiting only isotropic properties, of permanent magnets of iron-nickel-aluminium type exhibiting anisotropic properties in a preferred axis.

Before magnetisation, the ferrous nickel-aluminium alloy is subjected, whilst cooling from a temperature of at least 1000°C., to a mechanical pressure in a direction perpendicular to the preferred axis, the combination of pressure and temperature being such as to preclude appreciable mechanical distortion. The alloys covered contain nickel 20–32, aluminium 10–14, copper 0–7, optional additions of, *inter alia*, titanium, niobium, tantalum, silicon, zirconium, cerium and lanthium 0–5 per cent., remainder iron. The alloy may contain also up to 12–13 per cent

cobalt, in which case the limits of the nickel and aluminium contents decrease to, respectively, 14–20 and 7–10, per cent.

J. E. GOULD and W. WRIGHT. *Brit. Pat.* 817,702.

Nickel-Zinc Ferrites of High Initial Permeability

Ferromagnetic ferrites of improved initial permeability are produced by compacting a mixture of nickel oxide, zinc oxide, 0·04–1·5 mol per cent. of lithium oxide (or of a salt readily reducible to lithium oxide), and 49·7–50·3 mol per cent. of ferric oxide, and heating the compact in oxygen for 4 hours at 1250°–1300°C. A preferred composition has a mean grain-size of less than 20μ and contains: ferric oxide 49·7, nickel oxide 15·5, zinc oxide 34·8, lithium oxide 0·25, mol per cent.

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE.
Brit. Pat. 817,458.
Similar to *French* „ 1,160,127.

Chromium-Nickel-Molybdenum-Tungsten Tool Steels

The patent covers the use, as materials of construction for tools (e.g., riveting sets, pneumatic chisels, blanking or cold-headed dies, and machine screwdrivers) subjected to dynamic loads, of steels falling within the following composition range: carbon 0·65–0·85, silicon 0·50–2·50, chromium 1·20–2·50, nickel 0·30–1·00, molybdenum 0·30–1·50, per cent. The steels may contain also 0·2–1·0 per cent. of tungsten and/or 0·1–0·6 per cent. of vanadium.

Tests with pneumatic cold chisels are stated to have shown that the life of dressing-off chisels made from such steels is at least 25 per cent. higher than those fabricated from the hitherto used chromium-tungsten-silicon permanent steels, an increase which is attributed to the higher compressional strength of the former materials.

DEUTSCHE EDELSTAHLWERKE A.G. *Brit. Pat.* 820,705.
Similar to *Belgian* „ 557,904.

Nickel-Chromium-Molybdenum Precipitation-Hardenable Stainless Steel

A precipitation-hardenable stainless steel with corrosion-resistance comparable to that of the 18–8–Mo types of steel, and exhibiting, in the hardened condition, a minimum hardness of Brinell 400 (and preferably 500 or higher), falls within the following limits of composition: carbon 0·08 max., chromium 18–30, nickel 8–12, molybdenum 2–6, silicon 3–6, niobium 0·5–1·5, and, optionally, nitrogen 0·04–0·25, per cent.

N. S. MOTT, assignor to COOPER ALLOY CORPORATION.
Canad. Pat. 584,776.

Wrought Precipitation-Hardenable Stainless Steels

In the wrought condition, the precipitation-hardenable stainless steels to which the patent relates are, even when of substantial dimension and subjected only to slight reduction (as low as 50 per cent.), stated to be sound and of homogeneous composition, with copper-rich phase dispersed uniformly throughout; in the precipitation-hardened condition, the steels combine excellent mechanical properties with satisfactory welding characteristics.

The following composition range is claimed: chromium 15–18·5, nickel 2·8–5·6, copper 1–3, aluminium 0–0·2, tantalum+niobium 0–0·5, per cent.

W. C. CLARKE, assignor to ARMCO STEEL CORPORATION.
Canad. Pat. 585,831.

Chromium-Nickel Transformation-Hardenable Stainless Steels

The transformation-hardenable stainless steels covered by the patent fall within the following limits of composition: carbon 0·03–0·3, silicon 0·2–1·5, manganese 0·5–2·0, chromium 15–18, nickel 3–7·5, vanadium 0·55–1·75, per cent. The ferrite formers are so adjusted as to ensure that the M_s temperature is in the range 0° to −50°F. (−18° to −45°C.), and the steel is transformable, by sub-zero treatment, from a soft austenitic structure in the annealed condition to a hard martensitic structure. After hardening the steel may be tempered to improve its ductility.

A steel of the following composition is stated to exhibit, after suitable heat-treatment, a hardness in excess of Rc 45, or tensile strengths higher than 220,000 p.s.i. (92 t.s.i.: 155·5 kg./mm.²): carbon 0·15–0·26, silicon 0·35–0·75, manganese 0·75–1·2, chromium 16–17·3, nickel 3·4–5·6, vanadium 0·6–1·2, per cent.

R. SMITH, assignor to UNITED STATES STEEL CORPORATION. *U.S. Pat.* 2,894,867.

Nickel-base High-Temperature Alloys containing Boron and/or Zirconium Additions

The invention relates to nickel- or cobalt-base high-temperature alloys, the rupture-life, ductility, and creep-resistance of which are improved by addition of boron and/or zirconium. According to the claims of the patent, chromium and nickel and/or cobalt are melted *in vacuo* in the presence of carbon. The carbon deoxidation of the melt is allowed to proceed to substantial completion, and at least one of the highly reactive elements silicon, vanadium, aluminium, or titanium is added to the melt, the temperature of which is then adjusted to the desired tapping temperature. Finally, prior to tapping, boron and/or zirconium are added in amounts sufficient to complete the deoxidation of the melt and to provide, in the resulting alloy, 0·0005–0·05 per cent. boron and/or 0·005–0·5 per cent. zirconium.

Data exemplifying the improvements in properties achieved by the invention are presented for various nickel- and cobalt-base alloys.

UNIVERSAL-CYCLOPS STEEL CORPORATION.
Brit. Pat. 821,745.

Nickel-Chromium-base Thermocouple Element

The aim of the invention is to provide an electropositive thermocouple element which will conform to the standard E.M.F./temperature curve prescribed for the 'Chromel-P' elements of 'Chromel'/'Alumel' couples, and, at the same time, exhibit a minimum deviation from the standard curve when subjected to conditions involving, for example, 'green-rot' corrosion, sulphur attack, carburisation, oxidation, and vaporisation of the chromium. The element therefore possesses a maximum stability at elevated temperatures (1500°F. (815°C.) and above).

The element covered by the patent is made from an alloy consisting of: chromium 8·6–10, niobium 0·15–0·65, per cent., remainder nickel. Preferably the alloy also contains silicon 0·05–0·5, iron 0·25–0·75, and zirconium 0·05–0·15, per cent.

N. F. SPOONER and F. S. SIBLEY, assignors to HOSKINS MANUFACTURING COMPANY. *U.S. Pat.* 2,909,428.

Nickel/Mullite Sealing Rings and Bearings

A metal/ceramic material having increased resistance to seizing at high temperatures, and suitable for use in the fabrication of bearings and sealing rings, comprises a sintered mixture of finely powdered metal or metals of high melting point (50–90 wt. per cent.) and finely powdered ceramic material having a melting point higher than 1000°C. and a hardness less than that of corundum. The particle-size of each powder is sufficiently small to permit its passage through a mesh of gauge 300 B.S.S. or finer. The preferred metallic constituent is nickel (the nickel powder being produced from nickel carbonyl), and the preferred ceramic material is mullite.

MORGAN CRUCIBLE COMPANY, LTD.
(inventor, A. E. S. WHITE). *Brit. Pat.* 824,124.
Similar to *French* „ 1,178,078.

Nickel-containing Hard-Surfacing Alloy

Surface coatings, which are porous, readily machinable, and highly resistant to abrasion, corrosion and wear, are produced by spraying on to the workpiece (at a temperature in the range 1750°–1900°F. (955°–1035°C.)) a powder mixture consisting of a hard alloy of chromium, boron and nickel (the nickel comprising more than 50 wt. per cent. of the alloy) and a softer bonding metal. At the spraying temperature the individual particles become bonded together and form a cohesive coating in which the hard-alloy particles retain their identity.

The composition of the preferred hard alloy falls within the following range: nickel 65–85, chromium 8–18, boron 2–4·5, iron 1·2–5·5, silicon 1·2–5·5, cobalt 1·5 max., carbon 0·3–1, per cent. The soft bonding material, which comprises 20–70 wt. per cent. of the mixture, is preferably iron, cobalt, nickel, or an alloy based on at least one of these metals (18–8 stainless steel is specifically claimed).

WALL COLMONOY CORPORATION. *Brit. Pat.* 821,787.
Similar to *U.S.* „ 2,868,667.

Nickel-containing Spraywelding Material

The spraywelding material comprises a mixture of at least two powdered alloys (one a self-fluxing alloy) which are mutually alloyable below the upper fusion limit of the mixture when sprayed. The difference between the melting temperature of the self-fluxing alloy and that of at least one of the other constituents of the mixture is at least 10F°. The self-fluxing alloy contains phosphorus and/or lithium and/or boron, and is preferably a nickel-base alloy of the following composition: chromium 0–20, iron 0–10, molybdenum 3–10, copper 3–8, silicon 1–6, boron 1–6, carbon 0–1·5, wt. per cent., remainder nickel. The other constituent, which comprises 10–90 wt. per cent. of the mixture, is preferably nickel, an 18–8 or chromium stainless steel, or a nickel-chromium alloy.

Using such spraywelding materials, running and dripping and oxide formation during the fusing operation is minimised and a thicker coating is obtainable.

METALLIZING ENGINEERING COMPANY, INC.
Brit. Pat. 826,181.
Similar to *French* „ 1,172,214.

Corrigendum

Nickel Bulletin, 1959, vol. 32, No. 11.

In the references to papers abstracted under the heads given below, for *Trans. Metallurgical Soc., Amer. Inst. Mechanical Engineers*, read *Trans. Metallurgical Soc., Amer. Inst. Mining, Metallurgical and Petroleum Engineers.*

Heats of Formation of Copper-Nickel Alloys, p. 325.

Thermal Stability of Precipitation-Hardened and Dispersion-Hardened Nickel-base Alloys, p. 333.

High-Temperature Properties of Nickel- and Cobalt-base Alloys Melted and Cast in Air and *in Vacuo*, p. 335.

Mechanical Properties of Air-Induction- and Vacuum-Arc-Melted Heats of 'W-545' Alloy, p. 335.

Techniques for Growing Single Crystals of Austenitic Stainless Steel, p. 343.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

A Publication prepared by

DEVELOPMENT AND RESEARCH DEPARTMENT

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1